AUTONOMOUS SHIPS IN MARITIME LAW: CHALLENGES TO LIABILITY, SAFETY, AND SHIPPING PROTOCOLS

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DEGREE OF MASTER OF LAWS IN INTERNATIONAL TRADE LAW (2024 - 2025)

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CERTIFICATE

This is to certify that **Akshay Asok**, REG NO: **LM0224004** has submitted his Dissertation titled – "**Autonomous Ships In Maritime Law: Challenges To Liability, Safety, And Shipping Protocols**" in partial fulfilment of the requirement for the award of Degree in Master of Laws in **International Trade Law** to the **National University of Advanced Legal Studies, Kochi** under my guidance and supervision. It is also affirmed that the dissertation submitted by his is original, bona fide and genuine.

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DECLARATION

I, **Akshay Asok**, do hereby declare that this dissertation work titled "**Autonomous Ships In Maritime Law: Challenges To Liability, Safety, And Shipping Protocols**" researched and submitted by me to **the National University of Advanced Legal Studies** in partial fulfilment of the requirement for the award of degree of Master of Laws in **International Trade Law** under the guidance and supervision of **Dr. Balakrishnan K.**, **Associate Professor**, **the National University of Advanced Legal Studies** is an Original, Bonafide and Legitimate work. It has been pursued for an academic interest. This work or any type thereof has not been submitted by me or anyone else for the award of another degree of either this university or any other university.

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Contents

List of Abbreviations

Abbreviation	Expansion
AI	Artificial Intelligence
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs)
DNV	Det Norske Veritas
EU	European Union
IMO	International Maritime Organisation
MASS	Maritime Autonomous Surface Ships
MARPOL	International Convention for the Prevention of Pollution from Ships (MARPOL)
MSC	Maritime Safety Committee
SOLAS	Reframing Safety Standards Through Functional Equivalence
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
UMVs	Unmanned Maritime Vehicles
UNCLOS	United Nations Convention on the Law of the Sea (UNCLOS),1982

CHAPTER – I

INTRODUCTION

1.1. Autonomous Vessels: An Introduction

Since humans first walked the earth, we have been finding ways to make getting around easier. Fast forward to today, and we have built many transport systems to help us move.

However, a new challenge is on the horizon now, automation. It is already part of our daily lives and is used in several industries. In many areas, self-driving vehicles are becoming more common and changing how factories, warehouses, and ports work. Autonomous vehicles (AVs) have boosted productivity in industries that have adopted them. Since these vehicles do not rely on human labour and can operate non-stop, they offer greater efficiency. With minimal human involvement, the chances of mistakes or accidents are significantly reduced, making AVs a promising foundation for future industries. Even though AVs are currently used only in specific settings, their unique design makes them highly adaptable—especially in environments where it might be dangerous for humans to work. Intelligent and self-operating robots are becoming more central to economic growth and everyday life, often delivering more consistent and reliable results than people. That said, when it comes to vehicles, their use is still mainly limited to highly controlled environments with predictable paths. Passenger transport, in particular, draws the most attention and concern because safety must be ensured not just for passengers but for everyone around the vehicle. Although these are still overseen remotely, we are starting to see AVs in metro systems—like specific lines in Paris or Milan. The development of fully autonomous land, air, and sea vehicles is progressing more slowly, mainly because these modes are far more complex. Currently, these advanced AVs are primarily used in military settings, where the need for civilian safety is much lower. Still, the technologies developed for military use have the potential to be adapted for civilian transport in the future, provided they are handled with care and used for the right purposes.[1] These technologies are considered

[1] These types of vehicles are much more used for military than civil purposes. Their development is due to research in the military sphere by the governments of large nations such as the United States and Japan. The legal and technical issues of the military usage of self-driving vehicles, however topical and relevant, are not dealt with here. For more on this topic, please refer to B. Gogarty, M. Hagger, 2008, "The
Laws of Man over Vehicles Unmanned: The Legal Response to Robotic Revolution on Sea, Land and Air",

"disruptive" because they have the power to reshape industries and legal systems completely. While tech is advancing rapidly, lawmakers are struggling to keep up. There is already a lot of research around automated ships, and it is becoming increasingly clear that these futuristic transport systems could someday become the norm.[2]

1.2. Autonomous Vessel: Definition

In 2021, the International Maritime Organisation (IMO), during the 103rd session of its Maritime Safety Council (MSC), took an important step toward defining what an autonomous ship is. They introduced the term "Maritime Autonomous Surface Ships", or MASS, which includes all self-operating ships that travel on the surface of the water. This definition leaves explicitly out autonomous submarines, which are primarily used in military settings.

The MSC explained that MASS can operate with different levels of human involvement, and they outlined four degrees of automation:

> **Degree 1:** Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and sometimes unsupervised, but with seafarers on board ready to take control.
>
> **Degree 2:** Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
>
> **Degree 3:** Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
>
> **Degree 4:** Fully autonomous ship: The ship's operating system can make decisions and determine actions by itself.[3]

In the first two levels of automation, ships are only partially automated and still have crew members on board. Therefore, these vessels cannot be classified as unmanned. In "Degree 2", although the ship is remotely operated, it still has onboard crew and

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Journal of Law, Information and Science, Vol.19

[2] E. Van Hooydonk, 2014, “The law of unmanned merchant shipping – an exploration”, in “the journal of international maritime law” Vol. 20, pp. 403-406

[3] MSC 1 – Circular 1638, 3rd June 2021, “Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS)”. This document contains the first regulatory framework regarding Autonomous vessels. As of today, the document has no legal status.

facilities for transportation. However, in "Degrees 3 and 4", the vessels operate without crew. "Degree 3" involves remote control, while "Degree 4" signifies a fully autonomous ship capable of navigating to its destination on its own. For these fully automated vessels—Degrees 3 and 4—two types of Unmanned Sea Vessels (USVs) exist: remotely controlled vessels and autonomous vessels. In the case of remotely controlled ships, a human operator located onshore manages the vessel, guiding it through its journey. These ships are connected to a Shore Control Centre, which collects and processes data and then sends instructions to the ship. Although the ship carries out the navigation automatically, human input is still necessary to provide direction. Autonomous ships do not need anyone actively steering them, unlike remotely controlled ones. Once an operator sets the destination, the ship independently takes care of everything else. Its onboard systems—powered by artificial intelligence—handle navigation, cargo management, and engine control. The ship is packed with sensors that constantly collect data, which is then processed by computers to guide the ship's actions in real-time. While a command centre keeps an eye on things from a distance, people only step in if there is a safety concern or something unexpected comes up. Modern USVs often integrate both remote control and autonomous systems. The fundamental issue with these vessels is that they do not require humans onboard, raising significant legal and regulatory concerns under existing maritime laws and international agreements.[4] Even though the IMO has come up with a definition for autonomous ships in its Regulatory Scoping Exercise on Maritime Autonomous Surface Ships (MASS)[5], there is still an important question: Do our current laws recognize self-driving ships as "vessels"? We need to figure out this before going any further because it helps us understand whether existing maritime laws apply to these new types of ships or if we need to create entirely new rules just for them.

The tricky part is that there is no clear definition of what counts as a "ship" or "vessel" across international agreements. Ideally, we would have to go through all these

[4] H.Ringbom, 2019, "Regulating autonomous ships – concepts, challenges and precedents", Ocean Development & International Law, Vol. 50, pp. 148-149.
[5] MSC 1 – Circular 1638, 3rd June 2021, "Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS)". This document contains the first regulatory framework regarding Autonomous vessels. As of today, the document has no legal status.

conventions and legal systems to see if they cover autonomous ships or if these vessels fall through the cracks of the current legal framework. But for the sake of brevity, we will analyse the main International conventions on maritime law namely UNCLOS[6], SOLAS[7], MARPOL[8], COLREGs[9].

1.3. Literature Review

1. **Viatcheslav V. Gavrilov & Roman I. Dremliuga, *Major Issues of International Laws for Maritime Autonomous Vessels' Navigation*, 9 Res. Marine Sci. 442 (2024).**

Gavrilov and Dremliuga critically examine the inadequacies of existing international maritime law in regulating Maritime Autonomous Surface Ships (MASS). They argue that current legal frameworks—rooted in anthropocentric assumptions of the "pre-digital era"—are ill-equipped to handle the emergence of AI-operated vessels. The authors classify the legal challenges into three categories: (1) the anthropocentric bias of maritime conventions like UNCLOS, which presume human presence onboard; (2) the technical and legal unpredictability of AI systems, especially due to self-learning and non-determinism; and (3) the growing threat of cyberattacks, for which no targeted international legal protections currently exist. They emphasize that traditional legal concepts such as "master" or "crew" are difficult to transpose to AI-driven ships, and that regulatory assumptions about control, liability, and inspection must be revisited. Notably, the authors caution that simple reinterpretation of existing rules to fit autonomous vessels is not viable, given AI's distinct decision-making processes. Instead, they call for a fundamental rethinking of legal categories and the creation of new international norms specifically designed for MASS.

[6] United Nations Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 397 (entered into force Nov. 16, 1994). (herein after UNCLOS)
[7] International Convention for the Safety of Life at Sea, Nov. 1, 1974, 1184 U.N.T.S. 2 (entered into force May 25, 1980). (herein after SOLAS)
[8] International Convention for the Prevention of Pollution from Ships, Nov. 2, 1973, 1340 U.N.T.S. 61, as modified by the Protocol of 1978, Feb. 17, 1978, 1340 U.N.T.S. 184 (entered into force Oct. 2, 1983).(here in after MARPOL).
[9] Convention on the International Regulations for Preventing Collisions at Sea, Oct. 20, 1972, 1050 U.N.T.S. 16 (entered into force July 15, 1977) (herein after COLREGs)

The article underscores the urgency for proactive legal reform, particularly in cybersecurity, and warns that without international consensus, MASS could become vectors for legal ambiguity and illicit activities.

2. **Aldo Chircop, *Maritime Autonomous Surface Ships in International Law: New Challenges for the Regulation of International Navigation and Shipping*, in Cooperation and Engagement in the Asia-Pacific Region 18 (Myron H. Nordquist, John Norton Moore & Ronán Long eds., 2020**

Aldo Chircop's article explores the disruptive implications of Maritime Autonomous Surface Ships (MASS) for international maritime law, emphasizing both regulatory uncertainty and institutional inertia. MASS—defined by varying degrees of automation—pose challenges to conventions such as UNCLOS, SOLAS, and COLREGs, all of which presuppose human presence and control onboard ships. The author critically examines whether existing legal frameworks can be adapted through interpretation or whether substantive reform is required. Chircop highlights how traditional flag, coastal, and port state jurisdictions may struggle to uphold their duties, especially concerning safety, manning, liability, and inspection when MASS are controlled remotely or fully autonomous. He warns of complications in ensuring compliance, enforcing cybersecurity safeguards, and addressing legal accountability in the absence of onboard crews. The article commends the IMO's early steps, such as the 2017 scoping exercise, but stresses the need for a proactive, integrated, and systemic regulatory approach, avoiding piecemeal amendments. Chircop concludes by urging coordinated action to ensure that MASS are not only legally accommodated but do not receive preferential treatment that might undermine regulatory parity with crewed vessels.

3. **Don Martin, *No Auto Pilot as Autonomous Ships Tackle Liability, Legal and Operational Challenges*, Parker, Smith & Feek (July 18, 2024)**

Don Martin’s article provides an industry-focused assessment of the technological advancements, legal ambiguities, and operational risks associated with the deployment of Maritime Autonomous Surface Ships (MASS). Using the Japanese ferry *SOLIEL*'s[10] autonomous voyage as a case study, the article illustrates the rapid emergence of

[10] Japanese Consortium Ticks Off Autonomous Shipping Milestone, Nippon.com (Feb. 28, 2022), https://www.nippon.com/en/japan-topics/g02047/

automation in coastal navigation and highlights the pressing need for legal and regulatory adaptation. Martin critiques the current international maritime framework—comprising UNCLOS, SOLAS, COLREGs, and STCW[11]—for its human-centric assumptions, particularly in areas such as lookout requirements, crew qualifications, and emergency response. The article warns that fully autonomous ships (Level 4), which lack crew and even remote control, are incompatible with obligations such as rendering assistance under UNCLOS or maintaining a human watch as per COLREGs. A major contribution of this piece is its focus on liability and risk. It raises urgent questions about whether liability should rest with ship owners or shift to software manufacturers in cases of system failure. It also emphasizes cybersecurity as the most significant operational risk, warning of the potential for catastrophic interference if autonomous vessels are hacked. Furthermore, it discusses practical limitations in emergency responses, pollution control, and communication with Vessel Traffic Services (VTS). The article calls for a forward-looking, harmonized legal framework and emphasizes that any successful integration of autonomous vessels into global shipping must involve rethinking liability, cybersecurity, and human oversight in light of technological realities.

4. **Baris Soyer & Andrew Tettenborn, *Autonomous Ships and Private Law Issues*, in New Technologies, Artificial Intelligence and Shipping Law in the 21st Century 63 (Barış Soyer & Andrew Tettenborn eds., Informa Law 2020).**

Soyer and Tettenborn provide a rare, in-depth legal analysis of the private law challenges emerging from the commercial deployment of autonomous vessels. Their central thesis is that while most existing maritime private law regimes—such as those concerning collision, salvage, arrest, wreck removal, limitation of liability, and pollution—may broadly apply to autonomous ships, targeted clarifications and legislative reforms are essential to avoid ambiguity and insurance instability.

The authors argue that uncertainty in liability will deter investment and inflate insurance premiums, undermining the economic benefits of autonomous shipping. They critically examine whether current fault-based systems (e.g., the Brussels

[11] International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, July 7, 1978, 1361 U.N.T.S. 2 (entered into force Apr. 28, 1984), as amended. (hereinafter STCW)

Collision Convention 1910)[12] should continue or give way to strict liability regimes due to the unique decision-making patterns of AI, which can depart from predictable human logic.

They recommend:

- Reinterpreting "fault" to include AI system malfunctions;
- Assigning liability presumptively to the registered owner, even when control is outsourced;
- Clarifying salvage rights and obligations when remote operators or software consultants render aid;
- Adapting arrest mechanics to account for digital control codes;
- And ensuring autonomous ships are included under all relevant definitions of "ship" in liability and wreck removal regimes.

Importantly, the authors argue that public acceptance and ethical dilemmas (e.g., AI decision-making in collision scenarios) make a strict liability approach more suitable. They suggest that a comprehensive international convention on private law aspects of autonomous shipping may ultimately be needed.

5. **Baris Soyer, *The Future of Autonomous Shipping – The Regulatory Challenge*, in New Technologies, Artificial Intelligence and Shipping Law in the 21st Century 145 (Barış Soyer & Andrew Tettenborn eds., Informa Law 2020).**

Professor Baris Soyer offers a comprehensive and strategic evaluation of the regulatory hurdles facing the international legal system as it attempts to accommodate Maritime Autonomous Surface Ships (MASS). He argues that while the IMO has initiated important scoping exercises, much of the existing maritime legal framework—developed for human-operated vessels—is fundamentally incompatible with autonomous operations. Soyer identifies critical technical and legal mismatches in core conventions such as SOLAS, COLREGs, STCW, and UNCLOS. Issues range from compliance with human lookout requirements and bridge watch keeping to uncertainties in liability attribution when decision-making shifts from humans to artificial intelligence. He warns that incremental technological deployment (with

[12] International Convention for the Unification of Certain Rules of Law with Respect to Collisions Between Vessels, Sept. 23, 1910, 1913 Gr. Brit. T.S. No. 20, 212 Consol. T.S. 178.

variable autonomy levels during a voyage) complicates regulatory clarity and enforcement.

To resolve these challenges, Soyer proposes a dual-track solution:

1. Technical regulation should be handled through a new overarching IMO Code[13] (akin to the Polar Code), which amends key conventions using tacit procedures and establishes unified standards for remote operation, training, and cyber-resilience.
2. Private law issues, especially liability allocation, should be addressed through a separate international convention, potentially introducing strict liability for shipowners or other responsible actors. He emphasizes that liability clarity is crucial for insurers and manufacturers to confidently support the market.

Soyer ultimately advocates for regulatory realism—recognizing political fragmentation and the diversity of technological models—and calls for steady, inclusive, and technically-informed lawmaking that can evolve alongside MASS development.

6. Tore Relling & Jonathan Earthy, Legal, Regulatory, and Humans, in Human Factors for Maritime Autonomous Surface Ships 31 (Andy Norris & Robin Pitblado eds., CRC Press 2023)

This chapter, grounded in expert workshop discussions, explores the legal and regulatory challenges posed by the emergence of Maritime Autonomous Surface Ships (MASS), with a central focus on how evolving technology reshapes human roles and responsibility. The authors emphasize that current maritime laws, rooted in assumptions about crewed vessels, are ill-equipped to govern autonomy, particularly as autonomy shifts from individual ship functions to complex, system-based operations. A recurring theme is regulatory uncertainty: how can rules be developed when the full scope of autonomy is still undefined? Visionaries consulted in the HUMANE[14] project diverged on whether existing conventions (e.g., SOLAS, STCW, COLREGs) could be reinterpreted or whether wholly new frameworks are required. They stressed that

[13] Baris Soyer, Navigating the Legal Challenges of Maritime Autonomous Surface Ships, 2023
[14] Western Norway University of Applied Sciences, Human Maritime Autonomy Enable (HUMANE), https://www.hvl.no/en/project/591640/

ambiguous human-machine boundaries, cybersecurity, software assurance, and the role of shore control centers all demand regulatory attention. The chapter also raises concerns about liability in a post-human era, highlighting difficulties in assigning responsibility when ship operations are increasingly software-driven or remotely managed. The authors call for new liability models, possibly involving strict product or system integrator responsibility, and caution against assuming existing insurance models will suffice. Importantly, the chapter argues for the co-evolution of law and technology, rejecting a one-size-fits-all legal approach in favour of adaptive, data-informed, and human-centred regulation. It warns that fragmented, local rulemaking (if global consensus fails) could stifle innovation and create safety and legal risks.

7. **Tim Howse, Maritime Autonomous Surface Ships – Identifying and Covering the Risks, Gard (Oct. 21, 2024)**

This industry-focused article explores the emerging risk environment posed by Maritime Autonomous Surface Ships (MASS) and examines how traditional marine insurance frameworks must adapt to accommodate automation. Howse identifies key legal and operational challenges, particularly in areas like liability, cybersecurity, product risk, and regulatory lag. A major concern is the difficulty of applying fault-based liability regimes (e.g., under the 1910 Collision Convention) to AI-driven ships. The article questions whether artificial intelligence can be "at fault" and whether liability will shift from ship owners to software developers or systems integrators. It also flags limitations in existing liability caps under conventions like LLMC 1976[15], which refer to the "personal act or omission" of a human—problematic in the context of unmanned ships. Howse stresses the growing threat of cyber risks, especially with shore-based control centers vulnerable to attacks. Current marine property insurance often excludes cyber threats, while limited P&I Club coverage exists only under specific war risk extensions. He calls for innovative solutions, including the potential development of an international cyber fund and liability regime. Regarding product liability, the article notes that existing EU frameworks (e.g., Directive 85/374)[16] offer limited protection, particularly when defects relate to compliance with public standards or technological novelty. As autonomy expands, liability may shift from ship owners

[15] Convention on Limitation of Liability for Maritime Claims, Nov. 19, 1976, 1456 U.N.T.S. 221 (entered into force Dec. 1, 1986).
[16] Council Directive 85/374/EEC, 1985 O.J. (L 210) 29 (EC).

to manufacturers and software providers, challenging the traditional "funnelling" of risk through the ship owner. Ultimately, Howse calls for proactive collaboration between regulators, insurers, and industry stakeholders, suggesting that MASS will first reshape domestic shipping laws before global frameworks (e.g., IMO conventions) catch up.

8. **Simon Baughen & Andrew Tettenborn, *International Regulation of Shipping and Unmanned Vessels*, in New Technologies, Artificial Intelligence and Shipping Law in the 21st Century 1 (Barış Soyer & Andrew Tettenborn eds., Informa Law 2020).**

Baughen and Tettenborn provide a comprehensive analysis of the regulatory shortcomings and necessary reforms in adapting international maritime law to Maritime Autonomous Surface Ships (MASS), particularly those at autonomy levels 3 and 4 (remotely controlled without crew and fully autonomous ships). The authors systematically examine how key international conventions—particularly UNCLOS, SOLAS, STCW, COLREGs, MARPOL[17], and ISPS[18]—are embedded with assumptions about human presence on board, which render them incompatible with unmanned operations. A core issue is the definitional ambiguity of "master" and "crew". While some national definitions allow a land-based operator to qualify as a master, many legal instruments require physical presence on board, creating regulatory uncertainty. The chapter highlights several functional and legal conflicts such as:

- Lookout obligations (COLREG Rule 5) that assume human sensory input;
- Crew training and safety equipment requirements (SOLAS & STCW) that are redundant or inapplicable to unmanned ships;
- Legal responsibility and criminal liability, which become complex when no human is physically in command.

[17] MARPOL, supra note 8

[18] International Maritime Organization, International Ship and Port Facility Security (ISPS) Code, adopted under SOLAS Chapter XI-2, IMO Doc. SOLAS/CONF.5/34 (Dec. 12, 2002), entered into force July 1, 2004. (herein after ISPS)

- Documentary requirements, such as onboard carriage of liability certificates and compliance logs, which unmanned ships cannot fulfill.

They further stress the need to modernize cyber regulations, onboard autonomy standards, and communication protocols—arguing that new SOLAS chapters and updates to IMO instruments are essential. The authors also recommend integrating machine-learning reliability and software security into future compliance regimes. Ultimately, the article proposes a hybrid approach: reinterpreting some provisions while replacing others through new legal instruments, ensuring safe and lawful integration of autonomous vessels into international trade.

1.4. Research Problem and Justification

The integration of MASS into international shipping highlights critical gaps in maritime law:

Liability: Traditional maritime law is rooted in fault-based liability—how does this apply when decisions are made by algorithms or remote operators?

Safety Protocols: SOLAS and COLREGs mandate human oversight and decision-making—how are these enforced or adapted in autonomous systems.

Cybersecurity: MASS are inherently vulnerable to cyber threats, yet legal frameworks are underdeveloped in this area.

These legal ambiguities pose operational and insurance risks and may hinder regulatory compliance. The central problem this dissertation addresses is the inadequacy of current maritime regulations to govern autonomous vessels effectively. As international shipping evolves, international law must evolve concurrently to ensure safety, accountability, and sustainability.

1.5. Research Questions

Main Question:

1. How do autonomous ships challenge traditional international maritime regulations, and are current frameworks sufficient to govern them?

Sub-questions:

1. What are the gaps in UNCLOS, SOLAS, MARPOL and COLREGs in addressing the operations of MASS?
2. How should liability be assigned in cases involving autonomous vessel accidents or system failures?
3. Are current cybersecurity and safety regulations sufficient to address the risks posed by MASS?

What legal adaptations or new frameworks are necessary for effective regulation?

1.6. Research Objectives

1. To critically analyze the gaps in existing maritime conventions regarding application to autonomous ships.
2. To assess the legal implications of AI and remote-controlled systems concerning liability.
3. To evaluate the current safety and cybersecurity protocols in maritime law.
4. To propose amendments to international regulations to accommodate the realities of MASS

1.7. Research Statement:

The current international maritime legal framework is insufficient to effectively regulate autonomous vessels; substantial amendments are necessary to address the unique challenges they present.

1.8. Scope and Limitations

Scope:

- Focuses on international legal instruments: **UNCLOS, SOLAS, MARPOL, COLREGs**, and **IMO guidelines**.
- Examines legal challenges related to **liability, safety, cybersecurity**, and **insurance** in MASS operations.

Limitations:

- Excludes analysis of **national regulatory regimes**, except for comparative reference (e.g., EU, USA, China).
- Technological evolution may outpace current legal responses, potentially rendering some conclusions time-sensitive.

1.9. Methodology Overview

This research uses:

- **Doctrinal Legal Analysis**: Examining treaties and conventions through legal reasoning.
- **Comparative Analysis**: Evaluating how jurisdictions address similar challenges (e.g., autonomous vehicles).
- **Case Law Review**: Analyzing any available precedents involving automation, liability, and international shipping disputes.
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1.10. Structure of the Dissertation

1. **Chapter One - Introduction:**
   This chapter gives an Overview of the Dissertation. It will outline the research background, purpose and significance, research question, hypothesis, objectives, research methodology and the structure of the chapters.
2. **Chapter Two– Legal Gaps in the Current Maritime Framework**
   This chapter will examine Existing International Maritime Laws (UNCLOS, SOLAS, MARPOL, COLREGs, etc.), IMO's Preliminary Work on MASS, Identified Gaps and Ambiguities in Current Legal Frameworks, Conceptual Challenges in Defining Liability, Vessel Status, and Human Roles
3. **Chapter Three – Liability, Safety, and Cybersecurity in Autonomous Shipping**
   This chapter will examine Liability Attribution in the Context of AI and Automation, Insurance and Risk Management Challenges, Compliance with Safety Norms in the Absence of a Crew, Cybersecurity Vulnerabilities and Legal Implications
4. **Chapter Four – Comparative and Regulatory Analysis**
   This chapter will include a Comparative Study of Legal Approaches to MASS (EU, USA, China), Evaluation of Regional and National Strategies, Lessons from Other Sectors (e.g., Aviation, Road Transport), and Relevance for Maritime Law Reform
5. **Chapter Five – Proposed Legal Reforms and Policy Recommendations**

This chapter will include the Need for Legal Adaptation of International Maritime Instruments, Proposals for Amending UNCLOS, SOLAS, and COLREGs, New Definitions and Legal Standards for MASS, Liability Allocation Models (Ship owner, Software Provider, Insurer), Institutional Mechanisms and Enforcement Strategies, and Enhancing Cybersecurity and Safety Protocols.

6. **Chapter six** – **Conclusion**

   This chapter summarizes major findings on current International Maritime Law and its sufficiency or insufficiency in dealing with Autonomous vessels. It emphasizes the need for updated legal frameworks and harmonized international laws to address the challenges posed by Autonomous vessels.

CHAPTER 2

LEGAL GAPS IN THE CURRENT MARITIME FRAMEWORK

2.1 Introduction

As the maritime industry embraces the transition toward automation, the deployment of Maritime Autonomous Surface Ships (MASS) presents profound regulatory and legal challenges. These vessels, which may operate with varying degrees of human oversight, or none at all, are fundamentally incompatible with many of the assumptions embedded in existing international maritime conventions. Instruments such as the United Nations Convention on the Law of the Sea (UNCLOS)[19], the International Convention for the Safety of Life at Sea (SOLAS)[20], the International Regulations for Preventing Collisions at Sea (COLREGs)[21], and other foundational agreements were all developed in an era that presumed human agency, onboard command structures, and direct seafarer accountability. This chapter undertakes a detailed examination of the legal vacuum surrounding autonomous shipping, with a focus on identifying gaps, ambiguities, and conceptual incompatibilities within the current international maritime legal framework. It begins with a critical evaluation of how existing instruments apply or fail to apply to autonomous ships, followed by an overview of the International Maritime Organization's (IMO) preliminary work on MASS, including its Regulatory Scoping Exercise and the development of a proposed MASS Code. The chapter then explores unresolved legal uncertainties, including definitional gaps, enforcement limitations, and issues of human accountability in the context of machine-directed vessels. Ultimately, this chapter aims to establish that while the technological progression toward autonomous vessels is advancing rapidly, the law has not kept pace. The absence of binding, autonomous-specific legal norms at the international level not only creates uncertainty but also threatens the uniformity and predictability that global maritime law has traditionally provided. This sets the foundation for the discussions in the following chapters, which delve into liability allocation, safety regulation, and the urgent need for normative reform.

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[19] UNCLOS, supra note 6
[20] SOLAS, supra note 7
[21] COLREGs, supra note 9

2.2 UNCLOS

UNCLOS does not provide a general definition of "ship" or "vessel," apart from the specific definition of a "warship" in Article 29[22]. In the absence of a general definition, it is widely accepted that the term "ship" under UNCLOS can encompass any identifiable vessel used to navigate water. Notably, nothing in UNCLOS explicitly requires that a ship be manned by humans to qualify as a ship[23]. Scholars and jurists thus generally agree that unmanned vessels can fall within the category of "ships" under UNCLOS, provided they are capable of navigation and meet the basic criteria of a vessel in maritime usage[24]. This dynamic interpretation aligns with the principle of evolutive treaty interpretation, allowing UNCLOS terms to be read in light of technological developments[25]. One commentary notes that UNCLOS "does not directly recognize the existence of unmanned vessels." Yet, its principles and rules do apply to their operations, meaning that, in theory, unmanned vessels can be treated as ships under the Convention. Beyond UNCLOS itself, other international instruments support a broad notion of "vessel" that comfortably includes UMVs. For example, the International Regulations for Preventing Collisions at Sea (COLREGs) define "vessel" to include "every description of watercraft…used or capable of being used as a means of transportation on water"[26]. Similarly, the MARPOL[27] Convention (prevention of pollution) defines "ship" as "a vessel of any type whatsoever operating in the marine environment". Such definitions emphasize that the vehicle's function – navigation or transport on water – is key, regardless of whether humans are on board. Even a 1972 treaty (London Convention) defined a ship broadly as "any waterborne craft of any type whatsoever". These expansive definitions indicate that unmanned surface or underwater vehicles, if used for transportation or other maritime operations, are considered "ships/vessels" in the eyes of international law. In practice, states have the discretion to decide what constitutes a "ship" for flag registry purposes (as discussed below). UNCLOS Article 91 provides that every State may fix the conditions for granting its nationality to ships and registering ships under its flag[28]. This allows States

[22] UNCLOS, supra note 6, art. 29.
[23] UNCLOS, supra note 6, art .94; see also Marinfo, Unmanned Vessels and the Law, FAQ 1, https://www.marinfo.org/.
[24] Eric Van Hooydonk, The Law of Unmanned Merchant Shipping: An Exploration, 20 J. Int'l Mar. L. 403, 406 (2014).
[25] Vienna Convention on the Law of Treaties art. 31(1), May 23, 1969, 1155 U.N.T.S. 331.
[26] COLREGs, supra note 9, r. 3(a).
[27] MARPOL, supra note 8
[28] UNCLOS, *supra* note 6, art. 91.

to treat unmanned craft as registrable ships. Indeed, UNCLOS implicitly recognizes a State's authority to define and register new types of vessels, since registration rules are under exclusive flag State responsibility. Many States and the International Maritime Organization (IMO) are already moving in this direction by developing the concept of Maritime Autonomous Surface Ships (MASS) and adapting regulations for them. In short, given UNCLOS's broad and technology-neutral language, unmanned vessels can qualify as "ships" or "vessels" under the Convention. No clause in UNCLOS requires a crew on board for vessel status, and subsequent state practice reinforces the acceptance of UMVs as lawful ships.

2.2.1. Nationality, Registration and Genuine Link (Articles 90–92)

Under the United Nations Convention on the Law of the Sea (UNCLOS), unmanned vessels must possess nationality and be registered to a flag State, just as manned vessels are. Article 90 confirms that every State has the right to sail ships under its flag on the high seas, a right that applies equally to Maritime Autonomous Surface Ships (MASS), provided they are properly flagged.[29] Article 91 stipulates that ships must have a genuine link with the State whose flag they fly, leaving it to national laws to define registration criteria and vessel types, including unmanned ships.[30] This framework allows States, including land-locked ones, to register UMVs under domestic law, provided they exercise effective control—satisfying the "genuine link" requirement.[31] Several States have already begun pilot programs to register autonomous ships, aligning with Article 94(2)(a), which mandates maintaining a ship registry.[32]Once registered, the vessel obtains the right to fly the flag and becomes subject to the exclusive jurisdiction of the flag State, in accordance with Article 92.[33] An unmanned vessel that is not registered to any State would be considered stateless under UNCLOS, triggering enforcement measures such as interdiction or boarding under Article 110.[34] However, not all unmanned maritime platforms qualify as "ships." Very small autonomous devices used for marine scientific research may instead be classified as "equipment" under Part XIII of UNCLOS and would not enjoy navigational rights.[35] UMVs intended

[29] Id. art. 90
[30] Id. art. 91(1).
[31] Id
[32] Id. art. 94(2)(a); see also Int'l Mar. Org. [IMO], Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), MSC 102/5 (2021).
[33] UNCLOS, supra note 6, art. 92(1)
[34] Id. art. 110
[35] Id. arts. 245–262.

for sustained operation across maritime zones—such as cargo or naval units—are more appropriately treated as "ships," thereby falling within the flag State jurisdictional regime established under UNCLOS.

2.2.2. Flag State Responsibilities and Safety Obligations (UNCLOS Article 94)

Once a State registers an unmanned vessel, it assumes a full spectrum of responsibilities under UNCLOS Article 94. The general obligation in Article 94(1) requires each State to "effectively exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag."[36] This duty applies equally to MASS, even though several subsections of Article 94 presuppose a crewed vessel. For example, Article 94(3) addresses the manning and training of ships, and Article 94(4)(b) mandates that vessels be "in the charge of a master and officers who possess appropriate qualifications."[37] On the face of it, these provisions appear incompatible with crewless ships. However, several States and scholars support a functional interpretation: designating qualified shore-based personnel or remote operators as legal equivalents to onboard "masters" and "officers."[38] Jurisdictions such as Norway and Japan have already adopted such classifications in domestic legislation, allowing command authority to be exercised remotely.[39] This approach aligns with the object and purpose of UNCLOS, which aims to promote safety at sea—not to mandate the physical presence of crew where technological alternatives exist.[40] Such interpretations are further supported by Article 31(3)(b) of the Vienna Convention on the Law of Treaties, which allows subsequent State practice to inform treaty application.[41] The IMO's MASS scoping study and the increasing number of State-led autonomous shipping trials support the emerging consensus that "manning" includes remote supervision and failsafe systems. Article 94(3) also imposes concrete safety obligations, requiring that ships, manned or unmanned, be seaworthy and fitted with appropriate navigational and communication equipment.[42] For UMVs, this means the flag State must verify the reliability of sensors, autonomy software, and remote override systems. Moreover,

[36] Id. arts. 94(1)
[37] Id. art. 94(3), (4)(b)
[38] See Henrik Ringbom, *Regulating Autonomous Ships: Concepts, Challenges and Precedents*, 50 Ocean Dev. & Int'l L. 141, 154–55 (2019)
[39] Int'l Mar. Org. [IMO], Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), MSC 102/5/3 (2021).
[40] UNCLOS, supra note 6, preamble & art. 94.
[41] VCLT, supra note 25, art. 31(3) (b)
[42] UNCLOS, supra note 6, art. 94(3)(a).

compliance with internationally accepted safety standards, such as COLREGs, remains mandatory.[43]Additionally, under Article 94(4)(c), the flag State must ensure that the master and crew are familiar with applicable international regulations. In the context of UMVs, this extends to remote operators, AI supervisors, and potentially even software engineers responsible for pre-programmed behavior. If a vessel operates in a fully autonomous mode (i.e., with no human-in-the-loop), the flag State's role expands to certifying that the vessel's software can independently comply with conventions such as SOLAS, MARPOL, and COLREGs. In summary, while UNCLOS Article 94 was drafted for traditionally manned ships, its core obligations can be adapted to cover UMVs through progressive interpretation and evolving State practice.[44] No provision expressly prohibits unmanned ships; the legal burden lies with flag States to ensure that MASS meet safety, administrative, and accountability standards through effective oversight of both technology and shore-based command infrastructure

2.2.3. Duty to Render Assistance (UNCLOS Article 98[45]) and the Absence of Crew

UNCLOS Article 98(1) obligates flag States to ensure the "master of a ship" renders assistance to persons in distress at sea, provided it does not pose serious danger to the ship or its crew.[46] This human-centric duty presents challenges for unmanned vessels (UMVs) that lack onboard personnel. However, emerging legal interpretation suggests that the duty can still apply, provided flag States designate a responsible operator or entity to act in such circumstances.[47]In practice, a shore-based remote operator may serve as the de facto "master" of a UMV, directing rescue actions upon receiving a distress signal.[48] Some UMVs are equipped to relay emergency communications, deploy flotation devices, or maintain contact with castaways until help arrives.[49] Though their capacity to perform physical rescue is limited, they can still fulfill the core objectives of Article 98 through communication and surveillance functions. The duty is qualified by reasonableness—it only applies to the extent action can "reasonably be

[43] COLREGs, supra note 9, arts. 1–38
[44] UNCLOS, supra note 6, art. 94(1); see also Ringbom, supra note 20, at 157
[45]Ibid art. 98.
[46] Ibid art. 98(1)
[47] Ringbom, supra note 20.
[48] UNCLOS, supra note 6, art. 94(4)(b); see also Int'l Mar. Org. [IMO], Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), MSC 102/5/3 (2021).
[49] Id.

expected."[50] In the context of UMVs, this threshold is lower. While a manned ship might launch rescue boats, an unmanned vessel may only be expected to signal authorities or remain on scene as a beacon. Notably, there is no exemption from the duty simply due to the absence of crew; the flag State must ensure UMVs are not used in a way that undermines humanitarian obligations.[51] Even fully autonomous ships may be required to carry distress-detection sensors or default communication protocols. Some scholars argue that in such cases, the legal "master" could be assigned to a shore control center or, in the future, the operating system itself, under strict regulatory supervision.[52] As international maritime law evolves, the practical fulfillment of Article 98 by UMVs will likely depend on the flag State's regulatory framework and the technological capabilities of the vessel.

2.2.4 Navigation Rights of Unmanned Vessels (Innocent Passage, EEZ, High Seas)

Assuming an unmanned vessel is recognized as a "ship" under UNCLOS, it enjoys the same navigation rights as manned vessels, including innocent passage through territorial seas, transit passage through international straits, and freedom of navigation in exclusive economic zones (EEZs) and on the high seas.[53] UNCLOS does not condition these rights on the presence of a crew; instead, passage is defined by the conduct of the vessel, not its internal configuration.[54] A UMV engaged in continuous, non-prejudicial transit is therefore entitled to innocent passage under Article 17, provided it does not violate Article 19(2)'s list of prohibited acts.[55] Coastal States cannot arbitrarily deny innocent passage solely due to a vessel's unmanned status.[56] Moreover, Article 21(2) prohibits unilateral imposition of design or manning requirements unless they give effect to international standards, protecting unmanned vessels from discriminatory regulation.[57] Coastal States retain the right to regulate traffic for safety purposes under Article 22 and may deny passage under Article 25(1) if a UMV's activity ceases to be innocent.[58] Enforcement measures—such as diversion

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[50] UNCLOS, supra note 6, art. 98(1)
[51] See generally Erik Rosaeg, *The Duty to Rescue at Sea, in Light of Increasing Maritime Autonomy*, Nordisk Tidsskrift for Sjorett 165, 174–76 (2021).
[52] Ringbom, supra note 38, at 160.
[53] UNCLOS, supra note 6, arts. 17, 58(1), 87(1)
[54] Id. art. 19(1)
[55] Id. art. 19(2)
[56] Id. art. 17
[57] Id. art. 21(2).
[58] Id. arts. 22, 25(1)

or seizure—may be employed if proportionate and necessary. In practice, States may first attempt to contact the vessel's remote operator or flag State before taking action.[59]UMVs also enjoy transit passage rights under Part III of UNCLOS when navigating international straits, provided they adhere to norms such as proceeding without delay and avoiding interference.[60] While the absence of crew raises safety concerns, it does not negate the right itself. Littoral States may issue non-discriminatory safety guidelines, consistent with IMO practices, to mitigate risks.[61] On the high seas and within the EEZ, Articles 58 and 87 guarantee freedom of navigation for all ships, including UMVs.[62] The flag State maintains exclusive jurisdiction under Article 92, and other States may not interfere absent clear legal exceptions (e.g., piracy under Article 105, statelessness under Article 110, or illicit broadcasting under Article 109).[63] Being unmanned does not strip a vessel of its navigational freedoms or shield it from lawful interdiction. Port access, however, remains subject to coastal State consent. UNCLOS does not grant a right to enter foreign ports, except in distress situations under customary law.[64] States may lawfully impose entry conditions on UMVs—such as notification requirements, pilotage mandates, or technological certification—provided such conditions are reasonable, non-discriminatory, and serve legitimate safety concerns.[65] Blanket bans on all foreign UMVs may violate general international law if not objectively justified. In sum, UNCLOS's navigational regime is flexible enough to accommodate unmanned ships, preserving the balance between flag State rights and coastal State interests. As MASS technology becomes more prevalent, international guidelines (e.g., through the IMO) will likely refine these rights further to ensure safe, lawful integration of UMVs into global shipping lanes.

2.2.5 Jurisdiction and Enforcement Issues for Unmanned Vessels

UNCLOS maintains the flag State's primacy in jurisdiction over ships, including unmanned vessels. Article 94(2)(b) obliges the flag State to assume jurisdiction over its

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[59] See Erik Rosaeg, *The Regulation of Unmanned Ships and the Legal Challenges*, 47 Mar. Pol'y & Mgmt. 65, 71 (2020).
[60] UNCLOS, supra note 6, Part III.
[61] Id. art. 42.
[62] Id. arts. 58(1), 87(1).
[63] Id. arts. 92, 100–110.
[64] Id. art. 25(2); see also IMO, *Guidelines for Places of Refuge for Ships in Need of Assistance*, A.949(23) (2003).
[65] UNCLOS, supra note 6, art. 211(3); see also BIMCO, *Position Paper on Autonomous Ships and Port Access* (2022).

ships and those responsible for their operation, whether onboard or remote.[66] This includes responsibilities for registration, regulatory compliance, and penal or administrative measures if the vessel breaches international obligations (e.g., COLREGs or MARPOL).[67] For instance, Article 217 extends to UMVs, requiring flag States to enforce pollution standards on vessels flying their flag.[68] The jurisdiction of non-flag States is limited to established exceptions: piracy, statelessness, the slave trade, or unauthorized broadcasting.[69] While piracy under Article 101 refers to acts committed by a "crew or passengers," it is arguable that remote operators of UMVs constitute a vessel's crew for enforcement purposes.[70] In cases involving unmanned "pirate" vessels, States may act under Article 100 to repress such threats.[71] Likewise, an unflagged UMV can be approached or seized as a stateless vessel under Article 110.[72] Enforcement in coastal zones is permitted if the UMV violates local laws—such as illegal fishing in the EEZ (Article 73) or customs violations in the contiguous zone.[73] In these cases, enforcement actions may involve disabling or towing the vessel, since no onboard crew exists to arrest. Although the lack of crew simplifies enforcement in some respects, fully autonomous UMVs may pose operational challenges—requiring specialized boarding procedures or remote shutdown protocols.[74] Still, UNCLOS authorizes proportionate action where a vessel's passage is unlawful or poses a threat to coastal security (Article 25).[75] UNCLOS holds flag States accountable for the conduct of both commercial and State-operated unmanned vessels. Under Article 31, States are internationally responsible for wrongful acts by warships or other government vessels.[76] This extends to UMVs operated for research or defense purposes. Commercial disputes, including collision liability, fall under civil maritime law, but penal jurisdiction is primarily reserved to the flag State or the national State of the responsible operator under Article 97.[77] Where UMVs are controlled remotely, the

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[66] UNCLOS, supra note 6, art. 94(2)(b)
[67] Id.
[68] Id. art. 217.
[69] Id. arts. 100–110.
[70] See Henrik Ringbom, *Regulating Autonomous Ships: Concepts, Challenges and Precedents*, 50 Ocean Dev. & Int'l L. 141, 161–62 (2019).
[71] UNCLOS, supra note 6, art. 100.
[72] Id. art. 110.
[73] Id. art. 73.
[74] Erik Rosaeg, *The Regulation of Unmanned Ships and the Legal Challenges*, 47 Mar. Pol'y & Mgmt. 65, 73 (2020).
[75] UNCLOS, supra note 6, art. 25
[76] Id. art. 31.
[77] Id. art. 97.

operator's home State may share jurisdiction if the operator is considered "in service of the ship."[78] This interpretation allows for legal adaptation without contradicting the crew-based assumptions of UNCLOS. Moreover, Article 94(7) obliges the flag State to investigate serious casualties involving its ships, regardless of whether the vessel is manned or unmanned.[79] States are required to act upon credible reports of violations. Article 94(6) permits any State to report non-compliant ships to their flag State, which must then investigate.[80] Port and coastal States may also enforce domestic regulations in a non-discriminatory manner, consistent with UNCLOS. In emergency situations—such as a UMV drifting uncontrollably—nearby States may act in coordination with the flag State to mitigate threats. In summary, UMVs remain fully subject to the law of the sea, and enforcement regimes must adapt rather than retreat in the face of crewless technology. UNCLOS provides a robust framework for jurisdiction and accountability; the challenge lies in applying it pragmatically to the operational realities of unmanned vessels.

2.2.6. Unmanned Military Vessels: Warship Status and Sovereign Immunity

UNCLOS Article 29 defines a "warship" as a ship owned by a State's armed forces, bearing its national markings, under the command of a commissioned officer, and manned by a disciplined crew.[81] While unmanned naval vessels easily meet the first two criteria, they typically lack onboard command and crew, seemingly disqualifying them from warship status under a literal reading. This raises key legal questions. If unmanned vessels are not "warships," they may be denied privileges under UNCLOS, such as sovereign immunity (Article 95) and rights to exercise belligerent powers like the right of visit (Articles 107–110).[82] However, many States and scholars argue for a functional and evolutionary interpretation of Article 29, recognizing that the provision was drafted before the advent of MASS.[83] The central concern of Article 29—ensuring accountability and chain of command—can still be satisfied if a navy designates an

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[78] See generally IMO, *Legal Committee: Regulatory Scoping Exercise on Maritime Autonomous Surface Ships (MASS)*, LEG 105/11/1 (2020).
[79] UNCLOS, supra note 6, art. 94(7)
[80] Id. art. 94(6).
[81] UNCLOS, supra note 6, art. 29
[82] Id. arts. 95, 107–110.
[83] See Henrik Ringbom, Regulating Autonomous Ships: Concepts, Challenges and Precedents, 50 Ocean Dev. & Int'l L. 141, 163 (2019).

offboard commissioned officer and remote crew, all subject to military discipline.[84] Where the strict definition is not met, unmanned naval craft may be classified as "other government ships operated for non-commercial purposes" under Article 96.[85] These vessels still enjoy sovereign immunity on the high seas and in foreign territorial seas (Article 32), though they may lack certain warship-specific operational rights.[86] Legal practice is evolving. The United Kingdom has explicitly stated that remote-operated vessels can qualify as warships under UNCLOS, provided that the chain of command remains accountable and falls under military law.[87] This interpretation is gaining traction, supported by academic analyses such as Materna's argument for expanding the definition of warship to include unmanned platforms.[88] In any case, flag State responsibility remains central. Under Article 31, the flag State is liable for wrongful acts committed by its warships or government vessels.[89] If an unmanned naval vessel causes harm, such as a collision or unauthorized use of force, the State bears full legal responsibility, regardless of whether the act was committed by onboard crew, remote operators, or autonomous software.[90] The absence of human decision-makers on board does not dilute this obligation. From an operational standpoint, most current unmanned military vessels are remote-operated with human-in-the-loop systems, satisfying the UNCLOS requirement for a commissioned officer's command in practice.[91] Should fully autonomous naval craft emerge, new legal challenges will arise—particularly in relation to rules of engagement, accountability for automated force, and compliance with the law of armed conflict.[92] Until consensus emerges, the status of unmanned warships will likely depend on State practice and mutual recognition. The Vienna Convention on the Law of Treaties supports this: under Article 31(3)(b), consistent State practice and shared interpretation may evolve to treat unmanned naval vessels as

[84] U.K. Ministry of Defence, Maritime Autonomous Systems Strategy (2022); see also Erik Rosaeg, Legal Challenges in Military Uses of Maritime Autonomous Surface Ships, Nordisk Tidsskrift for Sjorett 95, 103 (2021).
[85] UNCLOS, supra note 6, art. 96.
[86] Id. art. 32.
[87] U.K. Ministry of Defence, supra note 84.
[88] Malgorzata Materna, Adjusting the Aperture: The International Law Case for Qualifying Unmanned Vessels as Warships, 35 Int'l J. Mar. & Coastal L. 85 (2020).

[89] UNCLOS, supra note 6, art. 31.
[90] See Int'l Comm. of the Red Cross [ICRC], *Autonomy, Weapons Systems and Accountability* (2016).
[91] See U.S. Navy, Unmanned Campaign Framework (2021).
[92] See UN Group of Governmental Experts [GGE], *Lethal Autonomous Weapons Systems Reports* (2017–2023).

warships.[93] As with the historical acceptance of submarines and aircraft carriers, international law may adapt to technological change by focusing on the State control and accountability rather than the physical configuration of a vessel.

2.3 Focus: SOLAS

The "International Convention for the Safety of Life at Sea" (SOLAS) is a significant convention for safety in the marine sector. It was originally introduced in 1914, following the tragic sinking of the RMS Titanic. Since then, it has been updated many times to address the changing needs and challenges of the shipping industry[94]. At its core, SOLAS is all about protecting lives at sea. It sets out safety rules that countries around the world must follow to ensure ships are built, equipped, and operated safely. These rules cover everything from how ships are designed and constructed to the kind of safety equipment they carry and how well the crew is trained. One of the key requirements under SOLAS is that every ship must carry enough life-saving equipment, such as lifeboats, life jackets, life rafts, and distress signals. These tools are essential for helping passengers and crew survive if something goes wrong. The convention also outlines strict standards for how ships should be built. They must be strong and stable enough to handle even the toughest conditions at sea. Ships must also have proper fire detection systems and modern navigation tools to help avoid accidents and respond quickly when problems arise. Another major focus of SOLAS is crew training. Everyone on board, from navigation officers to engineers, must be properly trained and certified. They must know how to handle emergencies, operate safety equipment, and navigate correctly to ensure the ship runs smoothly and safely. If a ship does get into trouble, SOLAS provides clear instructions on how rescue efforts should be carried out. Countries that have signed the convention must work together to set up rescue coordination centers and respond quickly to distress calls. Over the years, SOLAS has evolved with new technologies and changes in the maritime world. Today, it is one of the most widely recognized and followed international treaties. Thanks to SOLAS, countless lives have been protected, and it continues to play a vital role in making the seas safer for everyone.[95] According to Article II[96], the SOLAS Convention applies to

[93] VCLT, *supra* note 25, art. 31(3) (b)

[94] https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

[95] P. Pritchett, 2015, “Ghost ships: why the law should embrace unmanned vessel technology”. Tulane Maritime Law Journal, Vol. 40(1), pp. 208-210

[96] SOLAS, supra note 7, art. II (2) “The present Convention shall apply to ships entitled to fly the

"vessels flying the flag of contracting governments."[97] In general, unless there is a clear exception, its regulations are relevant only to "vessels engaged in international voyages."[98] However, the convention does not offer a precise definition of the term "vessel." Instead, it refers broadly to five main types: "passenger vessels,"[99] "cargo vessels,"[100] "tankers,"[101] "fishing vessels,"[102] and "nuclear vessels."[103] Unmanned Maritime Vehicles (UMVs), such as those considered in this dissertation, do not fit neatly into these categories, which casts doubt on whether SOLAS applies to their operations.

Despite this, there is a possibility that UMVs could still be seen as "cargo vessels," especially if they do not carry more than 12 passengers. Since "cargo vessels" are defined by exclusion (i.e., not being a "passenger vessel"), UMVs might fall under this umbrella, assuming they meet the broader criteria of what constitutes a "vessel." An "international voyage," as SOLAS outlines, involves travel between a contracting state and a port outside that state[104]. Many UMVs, however, operate domestically or are not port-dependent, meaning they may not technically qualify under this condition, making SOLAS inapplicable in some cases[105]. SOLAS also excludes "warships and troopships" and cargo vessels below 500 gross tonnage unless stated otherwise. While SOLAS does not explicitly define a "warship," it is typically interpreted in line with UNCLOS Article 29[106]. There is debate about whether remotely operated UMVs under military control could be considered "manned," but the general view is that they are not. If a UMV

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flag of States the Governments of which are Contracting Governments."

[97]SOLAS, supra note 7, Art. II

[98] Ibid

[99]SOLAS, supra note 7, ch I, reg. 2– Definitions (f): "A passenger ship is a ship which carries more than twelve passengers."

[100]SOLAS, supra note 7, ch. I , reg. 2– Definitions (g): "A cargo ship is any ship which is not a passenger ship."

[101]SOLAS, supra note 7, ch. I, reg. 2– Definitions (h): "A tanker is a cargo ship constructed or adapted for the carriage in bulk of liquid cargoes of an inflammable nature."

[102] SOLAS, supra note 7, ch. I, reg. 2– Definitions (i): "A fishing vessel is a vessel used for catching fish, whales, seals, walrus or other living resources of the sea."

[103]SOLAS, supra note 7, ch. I, reg. 2– Definitions (j): "A nuclear ship is a ship provided with a nuclear power plant"

[104] R. Veal, M. Tsimplis, A.Serdy, and A. Ntovas, S. Quinn, 2016, "Liability for operations in Unmanned Maritime Vehicles with Differing Levels of Autonomy", Chapter 4 "The Applicability of International Shipping Regulations to Unmanned Maritime Vehicles".

[105] Ibid

[106] UNCLOS, *supra* note 6, 29: "For the purposes of this Convention, "warship" means a ship belonging to the armed forces of a State bearing the external marks distinguishing such ships of its nationality, under the command of an officer duly commissioned by the government of the State and whose name appears in the appropriate service list or its equivalent, and manned by a crew which is under regular armed forces discipline."

carries weaponry, its status may warrant further legal scrutiny. Some legal scholars argue that if UMVs are recognized as vessels, they could be classified as "cargo vessels" within SOLAS, opening a path for legal inclusion. Moreover, Contracting Governments have the discretion to exempt ships with "innovative features" from certain SOLAS chapters such as II-1[107], II-2[108], III[109], and IV[110] when rigid application would hinder technological progress. In this light, unmanned operation could be interpreted as an "innovative feature," and strict enforcement—particularly of Chapter III, which deals with life-saving appliances—could inhibit development. These exemptions must, however, be addressed through the responsible Contracting Government Administration. There is also a provision within SOLAS for functional equivalency. If a regulation specifies a particular appliance, material, or provision, administrations may approve alternatives that offer an equivalent level of safety. This creates space for customized compliance pathways for UMVs when standard requirements present practical challenges. Still, it is essential to evaluate the complete SOLAS framework before determining which rules apply to different classes of vessels[111]. Regulation 33 of Chapter 5[112] is especially relevant: it places an obligation on the "master" of a ship at sea to assist anyone in distress. The absence of a master and crew on unmanned vessels complicates this duty. Whether a remote operator can fulfil this responsibility is a contested issue. Insights from a questionnaire[113] conducted by the International Maritime Committee[114] show that most countries reject the idea that the lack of a master

[107]SOLAS, *supra* note 7, ch. II-1 - Construction - Structure, subdivision and stability, machinery and electrical installations"

[108] SOLAS, supra note 7, ch. II-2- Construction - Fire protection, fire detection and fire extinction"

[109] SOLAS, *supra* note 7, ch. III- Life-saving appliances and arrangements"

[110]SOLAS, *supra* note 7 , ch. IV – Radiocommunications"

[111] R. Veal, M. Tsimplis, A.Serdy, and A. Ntovas, S. Quinn, 2016, "Liability for operations in Unmanned Maritime Vehicles with Differing Levels of Autonomy", Chapter 4 "The Applicability of International Shipping Regulations to Unmanned Maritime Vehicles".

[112] SOLAS, *supra* note 7, ch. V, reg. 33

[113] In 2017, the CMI (Comité Maritime International) submitted a questionnaire titled "Maritime Law for MASS" to its member states. This questionnaire aimed to understand the positions of different participating states regarding certain issues that arose with the introduction of autonomous ships. In 2018, these data were discussed at the CMI Assembly held in London. The website: https://comitemaritime.org/work/mass/ presents all the results, divided by country and cumulative, which emerged after the completion of the questionnaire. Among the various issues raised, there is also the one concerning the behavior that shipowners should adopt in the event of incidents involving the rescue of people at sea and how this may impact the introduction of crewless ships. Questions 3.1, 3.2, and 3.3 address this topic.

[114] The Comite Maritime International (CMI) is an international organization that deals with maritime law and legal issues concerning the maritime industry on a global level. Founded in 1897, the CMI brings together maritime law professionals from different nations and plays a leading role in the development, harmonization, and application of international maritime law. The CMI promotes cooperation among scholars, legal professionals, government representatives, and maritime industry organizations. Through

or crew justifies inaction during emergencies. For instance, U.S. domestic law[115] also mandates that vessels assist those in danger at sea. In practice, a remotely operated UMV could still offer help—by navigating toward the scene, relaying its position, providing temporary shelter, or sending data to shore-based responders. Similarly, China's Maritime Traffic Safety Law[116] requires vessels to try rescuing those in distress and notify authorities immediately. However, some nations take a different stance. The United Kingdom[117] maintains that the responsibility to assist lies with the "master" and only applies if the master can intervene. If an unmanned vessel lacks this capacity, the affiliated parties may not be held liable. Japan takes a firmer approach, suggesting that since unmanned ships have no crew, they are not obligated to assist[118]. Citing Regulation 33[119] specifies that the "master" should be "on board," Japan concludes that such vessels are exempt from this duty. Despite these varying views, the broader principle under SOLAS is that Contracting Governments must uphold safety at sea. Claiming the absence of a master as a legal defence does not relieve a vessel or its associated entities from responsibility. In fact, such a claim might increase liability. Such an approach would not facilitate the widespread use of unmanned ships in the

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meetings, conferences, and specialized committees, the CMI examines and analyzes emerging legal issues in the maritime field and develops tools and guidelines to address them. The organization focuses on a wide range of topics, including maritime transportation, maritime insurance, carrier liability, charterparty contracts, marine pollution, salvage, and much more. The outcomes of the CMI's work are often used as a reference source for governments, international organizations, and courts in maritime dispute cases. The CMI plays a crucial role in promoting cooperation and harmonization of maritime law on an international level, thereby contributing to the efficiency, consistency, and safety of maritime operations worldwide.

[115] U.S. Code 2304 - Duty to provide assistance at sea: "(1)A master or individual in charge of a vessel shall render assistance to any individual found at sea in danger of being lost, so far as the master or individual in charge can do so without serious danger to the master's or individual's vessel or individuals on board. […]".

[116] Maritime Traffic Safety Law of the People's Republic of China Chapter VII Articles 37-38: "Article 37: Vessels or installations involved in a collision shall exchange their names, nationalities and ports of registry and do their best to rescue personnel in distress. The vessels involved may not leave the scene of the accident without authorization, insofar as their own safety is not seriously endangered. Article 38: Upon receiving a request for rescue, the competent authority shall immediately organize a rescue operation. All units concerned and vessels or installations in the vicinity of the scene must act under the orders of the competent authority."

[117] The Merchant Shipping (Safety of Navigation) Regulations 2020

[118] According to the CMI questionnaire answer, Japan stated "The lack of an on-board crew can be a reason for not providing assistance of persons in distress at sea because the provision imposes the duty on the "master" of a ship. Regulation 33 of SOLAS Chapter V is provided on the assumption that the master is aboard the ship. Mariners Act Art. 14 and its Regulation Art 3 (1)-3 which implements SOLAS exempts the ship's master from pursuing the rescue action where she could not go to the rescue site with excusable reasons or in a special circumstance when it is not appropriate for her to go the rescue site or it is not necessary to do so"

[119] SOLAS, *supra* note 7, ch. V, reg. 33

international community[120]. Therefore, accountability should not rest solely with the master and crew. Shore-based operators, designers, and owners must also share this responsibility when an unmanned ship is at sea. Several SOLAS provisions pose practical challenges for UMVs. These include minimum manning requirements and obligations related to life-saving equipment. Chapter III, for example, requires vessels to carry life-saving appliances that satisfy the Administration. This is difficult to achieve when no one is on board for long periods. Chapter IV also mandates that personnel trained in radio distress communications must be present—another hurdle for unmanned operations where communications are handled from shore. Overall, most SOLAS rules presume the presence of a crew, and applying them blindly to UMVs could obstruct technological advancement. These regulations should be enforced only when practical and relevant for unmanned vessels. Fortunately, SOLAS offers some flexibility: Chapters 1-4[121] allow for exemptions when certain requirements could hinder innovation. Moreover, Resolution A.1047 (27)[122] encourages national administrations to adopt alternative arrangements in line with modern ship types and operations, so long as safety standards are upheld. Still, these allowances mostly concern ship construction and equipment. Key responsibilities—like ensuring navigational safety and the protection of life at sea—remain in effect. Therefore, future updates to SOLAS should address these functional challenges to accommodate the growing presence of UMVs[123].

2.4 Focus: COLREGs

Across international legal systems and under UNCLOS, every user of the sea is expected to uphold a duty of care—not only toward other maritime operators but also

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[120] According to R. Li, "On the Legal Status of Unmanned Ships", 2019

[121] SOLAS Convention, Chapter I - General provisions - Part A - Application, definitions, etc. - Regulation 4 – Exemptions, part (b): "(b). The Administration may exempt any ship which embodies features of a novel kind from any of the provisions of chapters II-1, II-2, III and IV of these regulations the application of which might seriously impede research into the development of such features and their incorporation in ships engaged on international voyages. Any such ship shall, however, comply with safety requirements which, in the opinion of that Administration, are adequate for the service for which it is intended and are such as to ensure the overall safety of the ship and which are acceptable to the Governments of the States to be visited by the ship. The Administration which allows any such exemption shall communicate to the Organization particulars of same and the reasons therefor which the Organization shall circulate to the Contracting Governments for their information."

[122] Resolution A.1047 (27) - PRINCIPLES OF MINIMUM SAFE MANNING Adopted on 30 November 2011 https://wwwcdn.imo.org/localresources/en/KnowledgeCentreIndexofIMOResolutions/AssemblyDocuments/A.1047(27).pdf

[123] R. Li, "On the Legal Status of Unmanned Ships", " China Oceans Law Review, vol. 2019, no. 4, 2019, pp. 165-190.

toward the marine environment itself. Since ships are the dominant means of transporting goods and people across oceans, clear and enforceable navigational standards are essential. This duty of care is often described using the term "good seamanship," which reflects not only safe navigation but also competent vessel management. The principle of "good seamanship" primarily ensures that mariners operate their vessels in a way that safeguards both those on board and others sharing the sea, as well as the broader ecosystem. Although "good seamanship" is a broad concept, the Collision Regulations—more commonly known as COLREGs—form a vital part of how this duty is practically enforced. Thus, the ability of an Unmanned Maritime Vehicle (UMV) to comply with COLREGs not only reflects its technological sophistication but also signals its readiness to coexist safely with traditional, manned vessels[124]. The International Regulations for Preventing Collisions at Sea, or COLREGs, establish rules intended to prevent ship-to-ship collisions. These rules are organized into five main sections. Part A lays out their general scope and applicability. Part B contains detailed rules regarding navigation, particularly steering and sailing. Part C outlines the required use of lights and shapes for identification, while Part D provides guidance on sound and light signals used in communication. Part E offers provisions for exemptions in special circumstances[125].

Part A – General Provisions

According to Rule 1, COLREGs apply "to all vessels upon the high seas and in all waters connected therewith navigable by seagoing vessels."[126] The term "vessel" is defined broadly to include "every description of water craft, including non-displacement craft, WIG craft and seaplanes, used or capable of being used as a means of transportation on water."[127] One of the cornerstone provisions, Rule 2, reinforces that merely following the COLREGs isn't enough to absolve a vessel, its "owner," "master," or "crew" from liability if they fail to take prudent precautions required by "common seafaring practices" or the unique circumstances of a situation. This rule emphasizes the need for human judgment and flexibility. It recognizes that rigid rule-following isn't always sufficient and that decisions must reflect practical seamanship.

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[124] A. Ntovas, M. Tsimplis, R. Veal, S. Quinn, A. Serdy, 2016, "Liability for operations in unmanned maritime vehicles with differing levels of autonomy", University of Southampton, Institute of Maritime Law, Southampton, chapter 4.3, pp. 62-63

[125] Technical Provisions https://www.imo.org/en/OurWork/Safety/Pages/Preventing-Collisions.aspx

[126] COLREGs, *supra* note 9, pt. A, r. 1(a)

[127] COLREGs, *supra* note 9, pt. A, r. 3(a)

This becomes particularly problematic when considering fully autonomous vessels. While remote operation may allow some degree of decision-making oversight, a completely unsupervised UMV is unlikely to meet the standards set by Rule 2.

Part B – Steering and Sailing Rules

Rule 5 requires that vessels maintain a "proper lookout" by using "sight, hearing, and all available means" to evaluate their environment and assess the risk of collision. The explicit mention of "sight" and "hearing" underscores the expectation of human involvement. Current autonomous systems that rely solely on sensors and algorithms would struggle to fully meet this requirement. Even in a world where only autonomous ships operate, any breach of *Rule 5* would technically still be considered a violation, as the rule presumes human sensory input[128]. That said, today's unmanned vessels often use advanced sensor technology to transmit real-time data to human operators onshore. This human element, although indirect, can help meet the expectations of *Rule 5*, especially if the data is promptly and accurately interpreted. Using electronic aids and shore-based monitoring doesn't violate the spirit of the rule, but more explicit regulatory guidance is still needed. *Rule 6*[129] builds upon this by stating that all vessels must maintain a "safe speed"[130] to ensure they can take proper action to avoid collisions and stop within an appropriate distance. Like *Rule 5*, this rule assumes human judgment in evaluating real-world variables like weather, traffic, and visibility. For UMVs, any delay in communications between the ship and its operator could affect how "safe speed" is determined. Similarly, *Rule 8* emphasizes that actions taken to avoid collisions must be decisive, timely, and reflect "good seamanship." If a UMV lacks the situational awareness to act proactively and appropriately, it may be unable to comply with these standards. Remote-controlled and supervised UMVs with immediate intervention capabilities are more likely to meet the intent of these rules, whereas fully autonomous, unsupervised vessels face substantial compliance challenges. Rule 18 addresses interactions between different vessel types and gives right-of-way to vessels that are "not under command."[131] This refers to ships that, due to unforeseen

[128] R. Veal, M. Tsinplis, 2017, "The navigation of Unmanned ships into the lex maritima", Lloyd's Maritime and Commercial Law Quarterly, pp. 303-335.
[129] P.K. Mukherjee, 2023, "Maritime Autonomous Surface Ships (MASS) : Precarious Legal Position of the Shore-Based Remote Controller", in "Autonomous Vessels in Maritime Affairs", Palgrave Macmillan, Cham ; Switzerland, pp.284-287
[130] R. Veal, M. Tsimplis, A. Serdy, 2019, "The Legal Status and Operation of Unmanned Maritime Vehicles", in "Ocean Development & International Law", Vol. 50, pp.37-39
[131] COLREGS Convention Part B, Rule 18, Responsibilities between vessels – part (a.i)

circumstances like engine failure, are unable to maneuver as required[132]. An unmanned vessel that loses communication or control might fall into this category though this is debatable. It's important to understand that "exceptional circumstances"[133] under this rule refer to unexpected technical malfunctions, not to the normal absence of human control in UMVs. Thus, using the rule as a blanket justification for the limits of autonomous ships could be problematic.

Parts C & D – Lights, Shapes, and Sound Signals

Parts C and D specify how vessels must use visual and sound signals to communicate their presence and intentions. These standards are technically demanding but essential for safety, particularly in busy or low-visibility environments. For UMVs to meet these requirements, their onboard systems must be capable of detecting and correctly interpreting signals from nearby vessels. They also need robust communication systems that remain functional even during routine signal losses or system glitches. In recognition of technological constraints, COLREGs allow governments to accept "closest possible compliance"[134] for vessels with "special construction or purpose." This flexibility means that unmanned ships with unique designs may be allowed slight deviations from standard signal placement or performance, provided this is approved by the relevant authorities. While the broad definition of a "vessel" under COLREGs might technically exclude some UMVs—particularly those not used for "transportation" on water—it doesn't mean UMVs can operate outside the rules altogether. On the contrary, COLREGs codify what's widely considered a minimum duty of care and "good seamanship" at sea. Ignoring these principles, even if they're not legally binding in every situation, could lead to liability for negligence or "fault" under common law systems. Critical rules like Rule 5 and Rule 6 demand that any vessel—whether manned or unmanned—be acutely aware of its surroundings, account

[132] According to R. Veal, M. Tsinplis, 2017, "The navigation of Unmanned ships into the lex maritima", Lloyd's Maritime and Commercial Law Quarterly, pp. 303-335.
[133] COLREGS Convention Part B, Rule3, General Application – part (f): "The term "vessel not under command" means a vessel which through some exceptional circumstance is unable to manoeuvre as required by these Rules and is therefore unable to keep out of the way of another vessel".
[134] 90 COLREGS Convention Part A, Rule 1, Application – part (e): "Whenever the Government concerned shall have determined that a vessel of special construction or purpose cannot comply fully with the provisions of any of these Rules with respect to the number, position, range or arc of visibility of lights or shapes, as well as to the disposition and characteristics of sound-signalling appliances, such vessel shall comply with such other provisions in regard to the number, position, range or arc of visibility of lights or shapes, as well as to the disposition and characteristics of sound-signalling appliances, as her Government shall have determined to be the closest possible compliance with these Rules in respect of that vessel."

for real-time environmental factors, and be capable of interpreting and reacting to navigational cues. As UMVs continue to evolve, their ability to meet these expectations will be central to their safe integration into shared maritime spaces[135].

2.5 Focus: MARPOL

MARPOL, the primary environmental treaty developed by the International Maritime Organization (IMO), focuses on preventing pollution from ships. It sets out a wide range of standards covering everything from vessel design and equipment, particularly for oil tankers, to detailed procedures for safe operations. These include rules limiting discharge into the ocean, protocols for ship-to-ship transfers, and mandatory reporting of pollution incidents. While MARPOL was crafted with traditional, crewed ships in mind, it is increasingly important for Unmanned Maritime Vehicles (UMVs) to comply with its provisions in the same way. Compared to some other IMO instruments, MARPOL's requirements may be more adaptable to unmanned operations, as they often relate more to equipment and environmental performance than to crew-specific actions.[136]

General Scope of Application

According to Article 3, MARPOL applies to ships that either fly the flag of a party to the convention or operate under the authority of such a party. The convention does not apply to "warships," naval auxiliaries, or other state-operated vessels used solely for non-commercial government service. However, even these exempted vessels are still expected to act "in a manner consistent with the convention," so long as it is "reasonable and practicable" and does not impair their operations[137]. This leaves the interpretation of such terms largely up to individual states, especially regarding military UMVs. Two main conditions determine whether a vessel falls under MARPOL: it must qualify as a "ship" according to the convention and be flagged or operated by a party to the agreement. The definition of "ship" may vary slightly across MARPOL's six annexes. Moreover, how states classify UMVs differs, leading to variations in national practice. Still, the principle of "no more favourable treatment" ensures that all ships, regardless

[135] A. Ntovas, M. Tsimplis, R. Veal, S. Quinn, A. Serdy, 2016, "Liability for operations in unmanned maritime vehicles with differing levels of autonomy", University of Southampton, Institute of Maritime Law, Southampton, chapter 4.3, pp. 71-72

[136] R. Veal, H. Ringbom, 2017, "Unmanned ships and the international regulatory framework", Journal of International Maritime Law, Vol. 23, p. 116.

[137] MARPOL, *supra* note 8, art. 3

of their classification or flag state, are held to equivalent standards when it comes to environmental protection. The convention defines "ship" broadly: "a vessel of any type whatsoever operating in the marine environment," including "hydrofoil boats," "air-cushion vehicles," "submersibles," and both "floating craft" and "fixed or floating platforms."[138] While this definition appears comprehensive, it lacks detailed criteria for each category, making its application somewhat ambiguous. Nonetheless, it is generally covered once a vessel fits this definition. Some scholars argue that if UMVs can discharge pollutants, they meet the purpose of the convention and therefore fall within its scope. Still, this leaves room for differing interpretations in national laws.

Detailed Analysis by MARPOL Annex

Annex I: Oil Pollution Prevention

Annex I governs operational discharges of oil and oily mixtures. Regulation 2 states the annex applies to all ships,[139] while Regulation 3 allows for construction-based exemptions if "equivalent protection" is ensured.[140] UMVs may qualify under this clause depending on their design and purpose. UMVs under 400 gross tonnage are subject to Regulation 14(4), requiring feasible retention or treatment systems for oily waste.[141] Regulation 15.6 permits limited discharge provided the vessel is "en route," equipped to limit discharge to ≤15 ppm, and not discharging from pump-room bilges or mixing waste with cargo residues.[142] Integrating compliant filtration and monitoring systems is thus critical for UMV legality under Annex I.

Annex II: Noxious Liquid Substances

This annex applies to ships carrying bulk hazardous liquids, a category not currently applicable to operational UMVs.[143]

Annex III: Packaged Harmful Substances

Annex III regulates packaged harmful substances per the IMDG Code.[144] While not typically triggered by UMV operations, scientific payloads containing hazardous

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[138] MARPOL, *supra* note 8, art. 2
[139] MARPOL Annex I, Reg. 2.
[140] Id. Reg. 3
[141] Id. Reg. 14(4).
[142] Id. Reg. 15.6.
[143] MARPOL Annex II.
[144] Id Annex III; see also Int'l Mar. Dangerous Goods Code (IMDG Code), 41–22 ed. (2022).

materials may fall under this annex. Even in the absence of a master or crew, port States could rely on Regulation 8 to inspect UMVs posing potential pollution risks.[145]

Annex V: Garbage Pollution

Applicable to all ships, Annex V restricts garbage discharges during normal operations.[146] Most UMVs generate minimal waste; nonetheless, they must comply where applicable.[147]

Annex VI: Air Pollution and Emissions

Annex VI addresses airborne pollutants and greenhouse gases. While many of its provisions apply to vessels ≥400 grt,[148] Regulations 12–14 on ozone-depleting substances, NO_x, and SO_2 emissions are relevant for any UMV using onboard combustion or refrigerants.[149]As UMVs increase in size and propulsion complexity, compliance with these environmental standards will become increasingly vital. While MARPOL's full framework may not yet uniformly apply to all UMVs, several core obligations—particularly under Annexes I, V, and VI—already affect their operations. As UMVs evolve in scale and functionality, ensuring proactive environmental compliance through design and documentation will be essential to meeting international maritime expectations.

2.6. IMO's Preliminary Work on MASS

The rise of Maritime Autonomous Surface Ships (MASS) presents an unprecedented challenge to the international maritime legal order, which has historically assumed the presence of human masters, officers, and crew on board vessels. In response, the International Maritime Organization (IMO)—the UN's primary regulatory body for global shipping—has initiated comprehensive preparatory work to assess how autonomous vessels may be integrated into existing legal frameworks. This preparatory work, although still in its early phases, represents a landmark shift in maritime regulatory thinking and offers critical insights into how international law might evolve to accommodate the technological transformation of shipping.

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[145] Id Annex III, Reg. 8.
[146] Id Annex V, Reg. 2.
[147] Id.

[148] Id Annex VI, Reg. 5.
[149] Id. Regs. 12–14.

2.6.1. The Regulatory Scoping Exercise (RSE): Objectives and Framework

In 2017, the IMO's Maritime Safety Committee (MSC) launched a Regulatory Scoping Exercise (RSE) specifically aimed at understanding how existing IMO conventions could be applied, adapted, or revised to address MASS operations[150]. The RSE was prompted by growing industry interest in autonomous vessels and by national experimentation with unmanned technologies, which threatened to outpace the development of uniform international standards. The RSE had both a descriptive and prescriptive function—it sought to catalog the limitations of existing law, while also identifying where legal reform might be necessary.

The RSE adopted a structured classification system that divided MASS operations into four distinct degrees of autonomy:

1. Ships with automated processes and decision support systems, operated by human crew onboard;
2. Remotely controlled ships with crew onboard;
3. Remotely controlled ships without crew onboard; and
4. Fully autonomous ships, with no human involvement in real-time operation or decision-making.

Each IMO legal instrument was examined to determine whether its provisions: (a) applied without change; (b) applied with clarification or interpretation; (c) required amendment; or (d) did not apply. This allowed a granular assessment of compatibility between MASS technologies and the current legal framework.

2.6.2. Key Findings and Legal Implications

The RSE revealed widespread dependence on human-centric concepts within current maritime instruments. Many legal provisions contain assumptions about human oversight, physical presence, and direct accountability—none of which are straightforwardly applicable to unmanned or algorithmically operated ships.

For example:

[150] Int'l Mar. Org., Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), IMO Doc. MSC 103/5/2 (May 2021).

- SOLAS contains numerous references to "manning," "master," "crew," and onboard procedures such as fire drills, navigation watch schedules, and distress responses[151].

- STCW deals entirely with training and certification of onboard personnel, without any provisions for shore-based or software "operators."[152]

- COLREGs, especially Rules 5, 6, and 8, assume sensory input by human lookouts and decision-making based on "good seamanship."[153]

- MARPOL requires onboard practices like Oil Record Book maintenance and pollution prevention measures undertaken by crew, which poses implementation challenges for unmanned vessels.[154]

These examples demonstrate that no major convention is fully applicable to all levels of MASS without significant legal reinterpretation or amendment. Fully autonomous vessels (Degree Four) raise the greatest legal uncertainty, particularly with respect to fault attribution, liability, and enforcement in the absence of onboard human actors.

2.6.3. The Draft MASS Code: A Work in Progress

Following the RSE, the IMO approved a Work Plan for the development of a non-mandatory MASS Code—a soft law instrument that will eventually serve as the foundation for a future binding legal regime[155]. Scheduled for adoption in 2025, the Code is designed to establish uniform, high-level objectives and functional requirements that flag States and shipping companies must meet when deploying MASS.

The MASS Code will address:

- Standardized definitions of autonomy and vessel classifications;

- Safety management systems for both onboard systems and remote operators;

- Shore-based control center regulations;

[151] SOLAS, supra note 7, ch. V, reg. 14, Nov. 1, 1974, 1184 U.N.T.S. 2.
[152] International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, July 7, 1978, 1361 U.N.T.S. 190.
[153] COLREGs, supra note 9
[154] MARPOL, supra note 8, Annex I, reg. 17
[155] Int'l Mar. Org., Work Plan for the Development of a Goal-Based Code for MASS, IMO Doc. MSC 105/15 (Apr. 2022).

- Data logging and cyber-resilience requirements;
- Human-machine interaction and emergency protocols.

The Code adopts a goal-based approach, meaning States have flexibility in how they meet the Code's functional safety outcomes, provided they can demonstrate equivalence with existing standards.

International Reception and Critique

While the MASS Code is widely seen as a step forward, it has been criticized for its non-binding nature, slow pace, and insufficient attention to fundamental issues like liability and enforcement. Several stakeholders have raised concerns that while technology is advancing rapidly, legal reform is lagging behind, potentially resulting in regulatory fragmentation as States adopt divergent domestic approaches. For instance, Norway, Finland, and Japan have already developed regulatory sandboxes or pilot schemes for MASS, creating the risk of inconsistencies unless harmonized through IMO frameworks[156]. Moreover, industry stakeholders have called for clearer guidance on certification of autonomous systems, insurance standards, and dispute resolution procedures. The current absence of binding global rules increases legal uncertainty, particularly in jurisdictions where MASS operations cross into foreign territorial waters. Despite these limitations, the IMO's scoping and drafting work on MASS signals an important commitment to future-proofing maritime law. The realization that traditional concepts such as "master," "lookout," and "manning" may need to be redefined or replaced reflects a shift from procedural formality toward functional accountability in maritime governance.

2.7 Identified Gaps and Ambiguities in Current Legal Frameworks

Despite the broad language and flexibility of existing maritime conventions, the integration of Maritime Autonomous Surface Ships (MASS) into the global shipping regime reveals numerous substantive and conceptual gaps. These gaps go beyond minor inconsistencies—they challenge the core assumptions of international maritime law, many of which are premised on the presence of human actors. While some ambiguities may be resolved through interpretation or soft law instruments, others highlight the

[156] Henrik Ringbom, Regulating Autonomous Ships—Concepts, Challenges and Precedents, 20 Ocean Y.B. 145, 158 (2020).

urgent need for structural reform and updated legal definitions that reflect the realities of unmanned navigation.

2.7.1. Absence of a Unified Definition of "Ship" or "Vessel" for Autonomous Technology

A central ambiguity is the absence of a uniform, technology-neutral definition of a “ship” or “vessel” across various conventions. While UNCLOS refrains from offering a general definition—apart from the specific definition of a “warship” under Article 29[157]—other instruments like SOLAS, MARPOL, and COLREGs use the term “vessel” without explicitly considering unmanned or autonomous modes of operation. This has led to jurisdictional inconsistencies, where states and courts interpret these terms based on traditional maritime concepts. As autonomous ships begin to operate without onboard crew, the question arises whether the legal status of a vessel is contingent upon human control. Scholars have increasingly argued for a functional approach to vessel classification—one that focuses on the ship's capability to navigate and perform maritime activities, regardless of human presence[158]. However, until such a definition is uniformly adopted by the IMO and incorporated into binding instruments, this ambiguity will persist and complicate registration, enforcement, and liability attribution.

2.7.2. Legal Uncertainty Around the Role of the Master and Crew

Many foundational conventions, particularly SOLAS and UNCLOS, assign legal duties and liabilities to a “master” or “officers” onboard[159]. For example, SOLAS requires ships to be “sufficiently and efficiently manned” and imposes obligations on the master in emergencies[160]. Similarly, UNCLOS Article 94(4)(b) obligates the flag State to ensure that “each ship is in the charge of a master and officers” with appropriate qualifications[161]. The emergence of fully autonomous MASS challenges this framework. If there is no physical master or crew on board, the current provisions cannot be satisfied without creative or expansive interpretation. Some jurisdictions have attempted to redefine the “master” as a shore-based remote operator, while others

[157] UNCLOS, supra note 6, art. 29
[158] Henrik Ringbom, Regulating Autonomous Ships: Conceptual and Practical Challenges, 20 Ocean Y.B. 145, 149 (2020).
[159] See generally SOLAS, supra note 7; UNCLOS, supra note 6, art. 94.
[160] SOLAS, supra note 7, ch. V, reg. 14.
[161] UNCLOS, *supra note* 6, art. 94(4)(b).

consider the possibility of assigning command authority to AI systems[162]. However, this raises serious issues of legal accountability, due process, and criminal liability, especially in incidents involving collisions, pollution, or unlawful conduct at sea.

2.7.3. Inadequate Framework for Liability and Insurance

Liability in maritime law traditionally hinges on human fault—negligence by the master, misconduct by crew, or failure to comply with navigational standards. This model becomes problematic in autonomous contexts where decisions are made by algorithms, and there may be no individual human operator at fault[163]. Furthermore, conventional insurance regimes, such as those developed under the International Group of P&I Clubs, are not yet tailored to assess risk for vessels without crew or under autonomous operation[164]. Existing legal frameworks offer little guidance on how to apportion liability between shipowners, software developers, remote operators, and manufacturers. This creates uncertainty not only for accident claims but also for flag States seeking to fulfill their due diligence obligations under UNCLOS Articles 94 and 217[165].

2.7.4. Ambiguity in Application of Navigation Rules (COLREGs)

The COLREGs, as noted earlier, are heavily reliant on human perception, judgment, and the concept of "good seamanship"[166]. Rule 5 requires that vessels maintain a "proper lookout by sight and hearing," while Rule 2 assigns liability not just for failure to follow rules but for failing to act with prudence in special circumstances[167]. Autonomous systems, even those using sophisticated sensors and AI, may not conform to the legal standard of "ordinary practice of seamen." Moreover, the rules provide little guidance on how unmanned vessels should interact with manned ones in shared waterways. Key questions—such as whether an AI-controlled ship can "see and avoid" other vessels with legal sufficiency—remain unresolved[168].

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162 Anna Petrig, Regulating Autonomous Ships: New Developments at the IMO, 53 Ocean Dev. & Int'l L. 1, 6 (2022).
163 Baris Soyer & Andrew Tettenborn, Liability for AI Decisions in Maritime Operations, in Maritime Liabilities in a Global and Regional Context 181 (2021)
164 International Group of P&I Clubs, Autonomous Vessels and Marine Insurance – Position Paper (2020)
165 UNCLOS, *supra note* 6, arts. 94, 217.
166 COLREGS, *supra note* 9
167 Id. rules 2, 5.
168 Petrig, supra note 162, at 8.

2.7.5. Limited Enforcement and Boarding Provisions for UMVs

UNCLOS provides a robust framework for maritime enforcement, including boarding rights, port State control, and coastal State intervention in cases of illegal activity[169]. However, these mechanisms are premised on the presence of crew. Article 110 allows warships to board foreign vessels to verify nationality or investigate specific offenses—but in the case of UMVs, it is unclear how boarding would proceed when there is no crew to question or arrest[170]. There is also ambiguity in determining how flag States are to exercise jurisdiction over remote operators or programming entities based in other states, particularly where these individuals may not be subject to the maritime jurisdiction of the flag State under existing rules[171].

2.7.6. Humanitarian Obligations and Rescue at Sea

One of the most pressing legal ambiguities arises in relation to UNCLOS Article 98 and SOLAS Regulation V/33, both of which impose a duty on the "master of a ship" to render assistance to persons in distress at sea[172]. Autonomous ships, by definition, lack an onboard master or crew capable of providing physical rescue. While some argue that remote operators could fulfill this obligation by directing the vessel to the scene, others question whether this is a legally sufficient response[173]. The ability of an unmanned vessel to conduct meaningful rescue operations—especially involving boarding survivors or providing aid—is extremely limited. Yet international maritime law considers this duty a core principle of customary and treaty law[174].

2.8. Conceptual Challenges in Defining Liability, Vessel Status, and Human Roles

The transition from human-operated ships to autonomous vessels presents not just technical or regulatory questions, but profound conceptual challenges that disrupt the foundational assumptions of maritime law. While the law has historically revolved around human responsibility, seafarer agency, and physical command at sea, the introduction of Maritime Autonomous Surface Ships (MASS) necessitates a re-examination of what constitutes a "vessel," who qualifies as a "master," and how legal

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[169] UNCLOS, supra note 1, arts. 25, 73, 94, 110.
[170] Id. art. 110.
[171] Id. art. 94(2)(b).
[172] UNCLOS, supra note 6, art. 98; SOLAS, supra note 2, ch. V, reg. 33.
[173] See Michael N. Schmitt, Autonomous Naval Weapons and the Duty to Render Assistance at Sea, in Autonomous Systems and the Law of Armed Conflict 141, 145–46 (2021).
[174] Id.; see also Douglas Guilfoyle, Shipping Interdiction and the Law of the Sea 151 (2009).

liability is assigned in the absence of direct human actors. These conceptual issues form the core of the uncertainty currently surrounding the international legal regime.

2.8.1 Rethinking the "Vessel" in Legal Terms

Under most maritime treaties—including UNCLOS, SOLAS, MARPOL, and COLREGs—the concept of a "vessel" or "ship" is central. However, these instruments seldom provide detailed or unified definitions. For instance, UNCLOS defines a "warship" in Article 29 but offers no general definition of "ship" or "vessel."[175] MARPOL and COLREGs adopt broad definitions such as "any watercraft used or capable of being used as a means of transportation on water."[176] This seemingly inclusive language appears to allow for the classification of autonomous craft as vessels. However, deeper examination reveals that these definitions assume that vessels are manned and that their actions are directed by seafarers capable of judgment and decision-making. The legal concept of a ship, in practice, has always included functional expectations—such as having a master in command, a crew onboard, and being subject to human discipline.

In the case of fully autonomous ships, these assumptions are strained. A software-driven, uncrewed platform may meet the physical criteria of a ship, but does it meet the legal and normative expectations historically attached to that status? If it cannot render assistance at sea, if it cannot be boarded or detained in the traditional sense, and if no human operator is directly accountable at sea, its classification as a "ship" becomes not merely a definitional matter but a conceptual rupture in maritime law.

2.8.2. The Dissolution of the Human "Master" Concept

The role of the ship's master is foundational in maritime governance. International conventions, flag State regulations, and customary practices all center on the authority, duties, and liabilities of the master. The master is tasked with maintaining order, ensuring compliance with regulations, responding to emergencies, and serving as the first point of legal responsibility. Articles 94 and 98 of UNCLOS, as well as SOLAS regulations and COLREGs obligations, all emphasize the centrality of the master in ship operation[177]. Autonomous ships, particularly those at Degree Three or Degree Four of autonomy (i.e., remote control without crew or fully autonomous), disrupt this legal

[175] UNCLOS, *supra note*.6, art. 29
[176] COLREGS, *supra note* 9
[177] UNCLOS, supra note 6, arts. 94, 98.

figure entirely. In such vessels, no human is physically present onboard, and decision-making may be distributed among teams or delegated entirely to machine learning algorithms.

This leads to two primary challenges:

1. Who qualifies as the master? Some legal scholars propose that remote operators be designated as "masters" in law, responsible for the vessel's decisions. However, in fully autonomous operations, no single person may have real-time control or situational awareness of the ship's activities.

2. Can machines exercise legal responsibility? The current legal system does not recognize artificial intelligence as a bearer of duties or liabilities. Therefore, assigning traditional "master" responsibilities to an AI-controlled system is incompatible with the existing structure of liability and enforcement.

2.8.3. Distributed Decision-Making and Fragmented Responsibility

Another conceptual issue concerns the disaggregation of authority in autonomous operations. In conventional shipping, the chain of command is clear—decisions flow from the master and crew under the oversight of the shipowner and flag State. In MASS operations, this hierarchy becomes fragmented. Decision-making may involve:

- AI systems operating based on pre-programmed logic or machine learning;
- Software engineers and system designers;
- Remote operators in land-based control centers;
- Network and communications infrastructure providers;
- Flag States and classification societies certifying MASS systems.

When an incident occurs—such as a collision or a pollution event—assigning legal responsibility becomes inherently difficult. Which of the above actors bears fault? If a software bug leads to a navigational error, is the developer liable under tort law? If the shipowner failed to update a control patch, do they bear strict liability? Is the flag State accountable for approving an unsafe autonomous system? These questions have no clear answers under existing maritime instruments, most of which assume that culpability will be assigned to the ship's master or the owner based on clear-cut human acts or omissions. The complexity of autonomous systems thus demands a rethinking of liability models—potentially moving toward joint liability, strict product liability, or tiered responsibility regimes involving all stakeholders in the operation of an autonomous ship[178].

2.8.4. Conceptual Mismatch with Seafarer-Based Standards

Many core international standards—especially those governing safety, training, navigation, and compliance—are premised on the human abilities of seafarers. For example, STCW requires certain hours of rest, certification exams, emergency drills, and manual watchkeeping duties[179]. These are not just operational requirements but reflections of a regulatory system built around human limitations and accountability. With autonomous vessels, these human-oriented safeguards lose relevance. There is no fatigue, no human error (in the conventional sense), and no crew to train or certify. Yet the replacement of human involvement introduces new types of risk—cybersecurity breaches, algorithmic unpredictability, and machine bias in decision-making. Current conventions provide no standards for certifying or inspecting software performance, AI decision protocols, or automated conflict-resolution systems.

2.8.5. Flag State Oversight and Accountability Redefined

Flag State responsibilities, as codified under UNCLOS Article 94, are premised on the notion that a State exercises “jurisdiction and control” over ships flying its flag, particularly in “administrative, technical, and social matters.”[180] However, in the case of MASS, especially fully autonomous ones, the exercise of “control” becomes abstract and indirect.

To fulfill these duties, flag States will need to develop new oversight mechanisms:

- Certification of autonomous software systems and decision-making architecture;
- Licensing of remote operators and control centers;
- Standards for cybersecurity, redundancy, and fail-safe mechanisms;
- Procedures for investigating accidents involving non-human actors.

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[178] Baris Soyer & Andrew Tettenborn, Liability for AI Decisions in Maritime Operations, in Maritime Liabilities in a Global and Regional Context 181 (2021).

[179] International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, July 7, 1978, 1361 U.N.T.S. 190.

[180] UNCLOS, supra note 6, art. 94

Failure to develop these frameworks may result in legal non-compliance with UNCLOS obligations, exposing States to international responsibility for acts committed by autonomous ships under their flag.

2.9.Conclusion

The legal framework governing the international maritime domain was never designed with the prospect of Maritime Autonomous Surface Ships (MASS) in mind. As this chapter has demonstrated, the existing conventions including UNCLOS, SOLAS, COLREGs, MARPOL, and STCW rest on assumptions that are increasingly incompatible with the realities of autonomous navigation. These assumptions include the physical presence of a master and crew, the exercise of human judgment in navigation, the ability to undertake rescue operations at sea, and the centrality of manned command structures in ensuring safety, compliance, and accountability. The IMO’s preliminary work, particularly through the Regulatory Scoping Exercise (RSE) and the ongoing development of a MASS Code, represents an essential first step toward modernizing the legal architecture. However, these efforts remain in the early stages, and their non-binding nature underscores the gap between technological innovation and regulatory preparedness.

From the analysis presented in this chapter, several critical gaps and ambiguities emerge:

1. Terminological and definitional uncertainties, especially regarding what constitutes a “vessel,” “master,” or “crew” in the context of unmanned operations.

2. Conceptual breakdowns in the liability framework, as traditional human fault models struggle to accommodate decision-making by AI and remote operators.

3. Incompatibilities between existing conventions and fully autonomous vessels, particularly in areas such as look-out requirements (COLREGs), crew certification (STCW), and emergency response (SOLAS, UNCLOS).

4. Jurisdictional and enforcement challenges, as flag States are confronted with new obligations to monitor and certify systems, software, and land-based operators that may not fall neatly within their existing legal competencies.

5. Absence of a global legal mechanism for assigning fault, resolving disputes, or enforcing penalties when autonomous systems fail or cause harm.

Moreover, the conceptual shift required to govern MASS—replacing human agency with distributed technological systems—forces a re-evaluation of long-standing legal doctrines such as command responsibility, seaworthiness, and due diligence. As autonomous shipping continues to evolve from experimental deployment to commercial reality, the urgency for reform becomes undeniable. Chapter 3 of this dissertation will explore in depth the liability challenges posed by MASS, focusing on civil, criminal, and insurance-related implications and assessing whether the current legal instruments can be adapted to manage this new maritime paradigm—or whether entirely new treaty instruments will be required.

CHAPTER 3

LIABILITY, SAFETY, AND CYBERSECURITY IN AUTONOMOUS SHIPPING

3.1. Introduction

Liability is the cornerstone of legal accountability in maritime operations. Whether the incident involves collision, pollution, salvage, or personal injury, the legal system provides mechanisms for identifying the responsible party and awarding compensation or imposing sanctions. In traditional maritime law, these mechanisms are relatively well-settled and revolve around the shipowner, the master, and the crew. Liability is generally based on established doctrines such as fault-based negligence, breach of duty of care, and strict liability in specific treaty contexts such as oil pollution or carriage of hazardous substances. However, the rise of Maritime Autonomous Surface Ships (MASS) destabilizes these core assumptions. These vessels, operating without seafarers onboard and often driven by artificial intelligence (AI) and automated decision-making systems, challenge the conventional attribution of fault. In a MASS setting, there may be no human master to hold accountable, no crew to blame for negligence, and no direct human intervention in the navigation or operation of the vessel at the time of an incident. This raises critical questions: Who is liable when an autonomous ship causes a collision? Who bears responsibility if the onboard system fails and environmental harm results? Can an algorithm be negligent? The answers to these questions remain largely unresolved, as current legal frameworks were designed for manned vessels and anthropocentric command structures. The absence of onboard human agency complicates not only the application of liability rules but also the triggering of insurance claims, the initiation of criminal proceedings, and the enforcement of port and flag State responsibilities.[181] This chapter explores the core legal challenges posed by autonomous ships with respect to civil, regulatory, and product liability. It begins with an assessment of the limitations of the existing legal architecture (Section 3.1), and then addresses how liability becomes fragmented across various stakeholders such as shipowners, software developers, control center operators, and manufacturers (Section 3.2). It further investigates emerging approaches in product liability, explores the challenges posed to cyber security, insurance markets, and reviews comparative and

[181] See Henrik Ringbom, Regulating Autonomous Ships: Concepts, Challenges and Precedents, 20 Ocean Y.B. 145, 149–51 (2020).

soft law developments from national and regional actors (Sections 3.3 to 3.5).The chapter aims to demonstrate that autonomous vessels do not simply require minor amendments to existing liability conventions, they necessitate a reimagining of the very foundations of responsibility in maritime law.

3.2. Existing Maritime Liability Frameworks and Their Limitations

International maritime law has developed over centuries, yielding a mature and structured liability regime for crewed ships. This regime is primarily composed of treaty instruments, case law, and customary practices. It typically rests on the presumption that human error is the most common cause of maritime incidents and that liability must be assigned to individuals or corporate entities exercising control over the ship[182].

3.2.1. Fault-Based and Strict Liability Models

Most conventional liability frameworks fall into one of two categories:

- Fault-based liability, where a claimant must prove negligence or misconduct. This is common in general maritime tort law, including personal injury, collisions under the Brussels Collision Convention 1910, or breach of contractual duties under carriage of goods conventions.[183]
- Strict liability, where responsibility arises regardless of fault. This model is used under the International Convention on Civil Liability for Oil Pollution Damage (CLC), where the shipowner is liable for pollution damage caused by the vessel, even without proof of negligence[184]. A similar approach exists under the HNS Convention for hazardous and noxious substances[185].

These regimes assume a direct link between an incident and a culpable human actor, such as a negligent master, a fatigued crew member, or a shipowner who failed to maintain equipment. However, in the context of MASS, this model begins to disintegrate. The "actor" may now be:

182 See generally Michael N. Tsimplis, Liability and Compensation in Case of Collision of Autonomous Ships: The Existing Legal Framework and Reform, 27 Mar. L. 58, 60 (2017).
183 Convention for the Unification of Certain Rules of Law with Respect to Collisions Between Vessels, Sept. 23, 1910, 1910 U.N.T.S. 116.
184 International Convention on Civil Liability for Oil Pollution Damage, Nov. 29, 1969, 973 U.N.T.S. 3.
185 International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, May 3, 1996, 35 I.L.M. 1406.

- An AI system executing pre-programmed instructions;
- A software program adapting its behavior through machine learning;
- A remote operator with delayed or partial visibility;
- A manufacturer or developer responsible for the system's design.

These new dynamics introduce indeterminacy in legal causation. If a MASS collides with another vessel due to a faulty navigational algorithm, should liability rest with the shipowner who deployed the system? The software developer who coded the navigational matrix? The flag State that certified the vessel? Or the remote control center operator who failed to intervene?

The difficulty is compounded by the fact that AI-driven systems do not make decisions based on human judgment, but on data processing, predictive analytics, and probability. Traditional standards such as the "reasonable mariner" test may be unfit to evaluate whether an autonomous ship's decision to change course was prudent[186].

3.2.2 Command Responsibility and the Breakdown of Seafarer-Based Attribution

Another pillar of maritime liability law is the principle of command responsibility. Under SOLAS and UNCLOS, the ship's master is the ultimate authority onboard, and the owner is responsible for ensuring that the vessel is seaworthy, adequately manned, and operated safely[187].The master has legal duties to render assistance at sea, comply with port State regulations, and respond to emergencies.

In a MASS regime, this structure collapses. There may be no human master onboard, and the notion of real-time "command" may be distributed across a remote control center, autonomous systems, and cloud-based navigation services. Consequently, it becomes unclear who should be held liable when things go wrong.

Flag State authorities, classification societies, and port States may also find it difficult to ensure compliance with safety and operational standards when decision-making is decentralized and non-human. For example, UNCLOS Article 94(4) requires the flag

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[186] Baris Soyer & Andrew Tettenborn, Liability for AI Decisions in Maritime Operations, in Maritime Liabilities in a Global and Regional Context 181, 185 (2021).
[187] SOLAS, supra note 7, ch. V, reg. 14

State to ensure that ships flying its flag are "in the charge of a master and officers." MASS may not comply with this formulation at all, creating a mismatch between treaty obligations and technological capabilities.

3.2.3 Enforcement and Jurisdictional Limitations

From a procedural standpoint, existing liability frameworks also rely heavily on the ability to investigate, attribute, and prosecute fault. This requires access to logbooks, witness testimonies, electronic records, and direct crew interaction. With autonomous ships, much of this evidence is replaced by machine data, software logs, and cloud-based command records.

Moreover, the absence of human actors onboard raises concerns about port State control, flag State jurisdiction, and the ability to carry out investigations or detain vessels[188]. Even if liability can be conceptually assigned, the practical enforcement of civil or criminal penalties becomes more complex.

In sum, the current liability frameworks assume a maritime world populated by human masters and seafarers. The rise of autonomous vessels fundamentally challenges this assumption. In the absence of targeted legal reform, the deployment of MASS risks operating in a legal grey zone where accountability may be diffused, delayed, or denied.

3.3. Fragmented Liability Among Multiple Actors

One of the most significant legal complications introduced by Maritime Autonomous Surface Ships (MASS) is the diffusion of liability across multiple, non-traditional actors. In contrast to conventional shipping, where the shipowner, master, and crew form the triad of legal responsibility, autonomous operations involve a broader and more technologically complex set of stakeholders. These include software developers, AI system providers, sensor manufacturers, remote-control center operators, cloud service providers, and flag State certifiers. Each may contribute in some way to the vessel's operation and, potentially, to an incident at sea.

This proliferation of actors fragments the previously centralized chain of responsibility and raises novel questions of causation, foreseeability, and attribution that current maritime legal regimes are ill-equipped to resolve[189].

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[188] Douglas Guilfoyle, Shipping Interdiction and the Law of the Sea 104–08 (2009).
[189] Henrik Ringbom, Regulating Autonomous Ships: Concepts, Challenges and Precedents, 20 Ocean Y.B. 145, 151 (2020).

3.3.1. Categories of Potentially Liable Parties

The following categories of stakeholders are commonly involved in the operation of an autonomous ship and may face legal scrutiny in the event of a maritime incident:

- **Shipowner/Operator**: While still the primary commercial entity associated with the vessel, the shipowner's direct control over operational decisions may be significantly reduced in a MASS context. Nonetheless, the owner typically bears residual liability and is often the insured party in maritime insurance policies[190].
- **Software Developers and AI Programmers**: The navigation, situational awareness, and decision-making functions of MASS are dictated by software, often designed and maintained by third parties. If an error in coding or machine learning leads to a collision or pollution incident, developers could be exposed to liability under product liability or tort law[191].
- **Remote-Control Center Operators**: In semi-autonomous systems, land-based personnel may monitor and occasionally override autonomous functions. If the control center fails to intervene appropriately or loses communication with the vessel, liability may shift to the operators, even if they are in a different jurisdiction[192].
- **Manufacturers of Sensors and Hardware**: Autonomous ships rely on integrated hardware—LIDAR, radar, GPS, communication modules, and propulsion systems—that may fail independently of software control. Component manufacturers could be drawn into litigation under principles of defective design or negligence[193].
- **Classification Societies**: These private entities assess the seaworthiness and safety of vessels and systems. If a MASS is certified despite known risks or

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[190] Barış Soyer, Autonomous Ships and Maritime Insurance: Problems and Perspectives, 27 J. Int'l Mar. L. 108, 112 (2021)
[191] Andrew Tettenborn, Product Liability and AI: Challenges in the Maritime Domain, in Maritime Liabilities in a Global and Regional Context 197, 199 (Baris Soyer & Andrew Tettenborn eds., 2021).
[192] Int'l Mar. Org., Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), IMO Doc. MSC 103/5/2 (May 2021).
[193] Soyer & Tettenborn, supra note 186, at 185.

flaws in the automation system, questions may arise about professional negligence or failure of due diligence[194].

- **Flag and Port States**: States that permit the registration or entry of autonomous vessels may also incur international responsibility under UNCLOS if they fail to enforce proper oversight or fail to prevent foreseeable harm from their flagged vessels[195].

3.3.2. Complex Causation and Legal Gaps

When incidents occur involving autonomous ships, causation becomes a multifaceted inquiry. For instance, suppose a MASS strikes a manned vessel after failing to recognize it in low-visibility conditions. The investigation might explore:

- Whether the sensor system failed to detect the vessel;
- Whether the AI logic misinterpreted the data;
- Whether the remote operator should have intervened;
- Whether prior maintenance of the systems was inadequate;
- Whether flag State certification failed to identify an operational risk.

This multi-node causation complicates liability determination in both civil and criminal contexts. Existing legal doctrines—such as proximate cause, joint tortfeasor liability, or vicarious liability, may offer partial solutions but are unlikely to be uniformly applicable[196]. Moreover, these doctrines vary significantly across jurisdictions, raising the risk of forum shopping, conflicting judgments, and fragmented enforcement.

3.3.3. Practical Barriers to Enforcement

Even if liability is theoretically assignable, practical obstacles may impede enforcement:

- Jurisdictional separation: Remote operators, software developers, and manufacturers may be located in different countries from the vessel's flag State or the site of the incident[197].

[194] Ringbom, supra note 189, at 155.
[195]UNCLOS, supra note 6. 94, 217, Dec. 10, 1982, 1833 U.N.T.S. 397
[196] Michael N. Tsimplis, Liability and Compensation in Case of Collision of Autonomous Ships: The Existing Legal Framework and Reform, 27 Mar. L. 58, 68–70 (2017).
[197] [Douglas Guilfoyle, Shipping Interdiction and the Law of the Sea 104–08 (2009).]

- Data access: Investigating parties may require access to black box-like systems, operational logs, and proprietary code, which may be confidential or encrypted.
- Chain of subcontracting: Many MASS systems involve layered outsourcing, where one contractor builds on or modifies another's system, blurring responsibility.

Additionally, the lack of precedent for many MASS-related incidents means that courts and arbitral tribunals may rely heavily on analogies, expert evidence, and soft law instruments, leading to inconsistent and unpredictable outcomes[198].

3.3.4. Need for Integrated Liability Models

Given the fragmented operational model of MASS, scholars and policy bodies have proposed integrated liability frameworks to address the multiparty nature of autonomous shipping. These may include:

- Enterprise Liability: Holding the shipowner strictly liable for all operations, regardless of delegation to AI or remote actors, with the option to seek indemnity from subcontractors[199].
- Product Liability Frameworks: Treating the AI system and related components as "products" under existing product liability laws, thus channeling fault to designers and manufacturers.
- Layered Liability Regimes: Assigning primary, secondary, and residual liabilities across different parties based on the nature of their involvement and level of control[200].
- Insurance Pools: Encouraging the development of shared risk mechanisms (e.g., P&I club extensions) to address uncertainty and cover liability gaps during the regulatory transition[201].

Until a unified international legal framework emerges—possibly under the auspices of the IMO or UNCITRAL—the fragmentation of liability in MASS operations will continue to pose a serious barrier to legal certainty and operational confidence.

[198] Petrig, supra note 3, at 7–8.
[199] Tsimplis, supra note 6, at 72.
[200] Soyer & Tettenborn, supra note 186, at 190.
[201] International Group of P&I Clubs, Position Paper on Autonomous Vessels and Insurance Risk (2020).

3.4. Product Liability and Autonomous Maritime Technologies

As Maritime Autonomous Surface Ships (MASS) increasingly rely on integrated software, sensors, and machine-driven processes, a fundamental shift is occurring in how liability may be distributed when harm results. In conventional maritime law, liability typically attaches to human actors or corporate shipowners. In contrast, autonomous systems rely on complex machinery and algorithmic logic, making product liability—a concept rooted in industrial and consumer safety law—an increasingly relevant avenue of redress[202]. This section explores how traditional product liability principles may apply to the maritime sector, particularly with respect to autonomous technologies, and what gaps remain in adapting these principles to the operational realities of MASS.

3.4.1. Traditional Product Liability Doctrines

Product liability law broadly assigns responsibility to manufacturers, designers, and distributors of defective products that cause harm. The three classic grounds for liability are:

1. Manufacturing Defect – Where the product deviates from its intended design.
2. Design Defect – Where the product is inherently dangerous even when properly manufactured.
3. Failure to Warn – Where the product is dangerous in foreseeable ways and no adequate warning is provided[203].

These doctrines have been widely applied in aviation, pharmaceuticals, and consumer goods, but their application in maritime contexts—especially involving complex, AI-driven systems—remains relatively underdeveloped. The product in the case of autonomous shipping may include:

- AI software guiding vessel decisions;
- Sensor arrays that detect obstacles and weather conditions;
- Machine learning modules that adapt the vessel's navigation in real time;

[202] Andrew Tettenborn, Product Liability and AI: Challenges in the Maritime Domain, in Maritime Liabilities in a Global and Regional Context 197, 199 (Baris Soyer & Andrew Tettenborn eds., 2021)

[203] Restatement (Third) of Torts: Prods. Liab. §§ 2, 10 (Am. L. Inst. 1998).

- The vessel's integrated control interface, propulsion systems, and communication networks.

Should any of these components malfunction, resulting in a collision or environmental hazard, product liability claims could arise against system designers, manufacturers, or integrators, depending on the origin of the defect[204].

3.4.2. Challenges in Applying Product Liability to MASS

Despite its potential, applying product liability law to autonomous ships raises multiple challenges:

- Determining the "Product": The line between product and service is blurred in autonomous systems. Is AI decision-making a product, or a service executed through a system? If the algorithm learns and adapts post-deployment, is the developer still liable for its evolved behavior?[205]

- Complex Causation: In traditional product liability, causation is relatively linear. A defective brake causes a crash. In MASS, a navigation error might stem from a confluence of hardware malfunction, sensor misreading, outdated software updates, or even improper machine learning inputs. Parsing out the causal chain is complex and highly technical[206].

- Lack of Uniform Maritime Product Liability Standards: There is no international convention or uniform customary law governing product liability at sea. Maritime claims are usually handled through contract law, torts, or the Hague-Visby Rules for cargo—none of which easily accommodate software defects in navigation systems[207].

- Autonomous Evolution and Software Updates: Autonomous vessels may receive over-the-air updates or adapt through machine learning over time. This raises questions of ongoing liability—does the original developer remain liable

[204] Baris Soyer, Autonomous Ships and Maritime Insurance: Problems and Perspectives, 27 J. Int'l Mar. L. 108, 114 (2021).
[205] Gianclaudio Malgieri, Liability for AI Decision-Making: A European Perspective, 9 J.L. & Tech. 1, 15–17 (2020).
[206] Michael N. Tsimplis, Liability and Compensation in Case of Collision of Autonomous Ships: The Existing Legal Framework and Reform, 27 Mar. L. 58, 66 (2017).
[207] See generally Hague-Visby Rules, International Convention for the Unification of Certain Rules of Law Relating to Bills of Lading art. IV, Aug. 25, 1924, as amended by Protocols of 1968 & 1979.

for all future behavior? Or should responsibility shift to the operator maintaining and updating the software?[208]

- Evidentiary Burdens: Product liability cases typically require proof of defect, injury, and causation. In the case of MASS, accessing system logs, proprietary code, or encrypted AI behavior may be impossible without robust forensic tools or regulatory authority, thereby hampering litigation[209].

3.4.3. Comparative Jurisprudence and Developments

Although maritime product liability for autonomous ships is still in its infancy, lessons may be drawn from related sectors, such as:

- Automated vehicles: In the automotive industry, courts and legislators in jurisdictions such as the EU and California are developing principles for assigning fault in self-driving car accidents, including manufacturer liability for algorithmic failure[210].
- Aviation systems: Product liability has been firmly established in aviation, particularly in cases involving faulty avionics or sensor data leading to crashes (e.g., the Boeing 737 MAX litigation)[211].

Within the European Union, the proposed revision of the Product Liability Directive (85/374/EEC) includes a broadened scope to cover digital products, software updates, and autonomous systems. It explicitly recognizes that AI-driven technologies may fall under strict liability for producers and developers when malfunctions result in harm[212]. These developments, though not maritime-specific, offer insight into how a hybrid liability model may be built—one that merges elements of strict liability for technological defects with conventional fault-based frameworks for operational negligence.

3.4.4. Future Directions for Maritime Product Liability

To accommodate MASS, international maritime law may eventually require:

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[208] Tettenborn, supra note 202, at 202.
[209] Soyer, supra note 204, at 115.
[210] European Parliament Resolution of 20 October 2020 on Civil Liability Regimes for Artificial Intelligence, EUR. PARL. DOC. 2020/2014(INL) (2020).
[211] In re Lion Air Flight JT 610 Crash, No. 18-cv-07686 (N.D. Ill. 2019).
[212] European Commission, Proposal for a Directive on Liability for Defective Products, COM(2022) 495 final (Sept. 28, 2022).

- A specialized legal framework for autonomous maritime technology liability, potentially as an annex to a revised SOLAS or as a standalone instrument.
- Expanded definitions of product and defect to include evolving software behavior and adaptive decision-making systems.
- Shared liability regimes recognizing the collaborative nature of MASS design, where developers, manufacturers, and integrators all contribute to the final system.
- Mandatory data preservation and access protocols to ensure forensic traceability of system decisions in the event of disputes[213].

As MASS becomes commercially viable, flag States and classification societies will play an increasingly important role in defining standards for technological certification, potentially influencing liability thresholds and defenses[214].

3.5. Cybersecurity Vulnerabilities in Autonomous Maritime Systems

The integration of digital technologies in maritime transport, especially in Maritime Autonomous Surface Ships (MASS), has introduced unprecedented cybersecurity risks. A successful cyberattack on a Degree 4 autonomous ship could endanger not just cargo, but also port infrastructure and public safety.[215]

3.5.1. Emerging Threat Landscape

Modern ships increasingly rely on AI, IoT, big data, and satellite navigation systems, embedding them into a complex digital ecosystem. While digitalization enhances efficiency, it also expands the attack surface.[216] Navigation systems like AIS, GNSS, and ECDIS are vulnerable to spoofing, jamming, and ransomware.[217] Ports and ships face persistent threats, from phishing and malware to software update exploits and unsecured USB access.[218] The use of outdated hardware, administrative login defaults,

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[213] Int'l Mar. Org., Outcome of the Regulatory Scoping Exercise for the Use of MASS, IMO Doc. MSC 103/5/2 (May 2021).
[214] Henrik Ringbom, Autonomous Ships and the Role of Flag States, 53 Ocean Dev. & Int'l L. 1, 6 (2022).
[215] Int'l Mar. Org. [IMO], Maritime Autonomous Surface Ships: Regulatory Scoping Exercise, MSC 102/5/3 (2021).
[216] UNCTAD, Review of Maritime Transport 2020, U.N. Doc. UNCTAD/RMT/2020 (2020)
[217] U.S. Dep't of Transp., Maritime Admin. [MARAD], Maritime Advisory 2020-016: GPS Interference Reports (2020).
[218] Astaara Company Ltd. & British Ports Ass'n, The Risk of Cybercrime to Maritime Infrastructure (2020).

and poor cybersecurity training exacerbates vulnerabilities. Even newer ships with advanced systems often lack sufficient security protocols.[219]

3.5.2. Legal and Structural Gaps

There is no binding international convention on maritime cybersecurity. While the IMO has issued Guidelines on Maritime Cyber Risk Management, these remain voluntary.[220] Regulatory fragmentation persists, and many flag States lack specialised cyber oversight agencies. Some countries, like Italy, have reassigned maritime cybersecurity to homeland security bodies, raising concerns over maritime-specific expertise.[221] The 2020 and 2021 *UNCTAD Review of Maritime Transport* emphasized that cyber risks are underreported and investment in mitigation is insufficient.[222] A 2020 white paper by Astaara estimates that maritime cybercrime contributes to a global loss of $2 trillion annually, while maritime cybersecurity spending remains disproportionately low.[223]

3.5.3. Key Vulnerabilities and Response Measures

The IMO identifies eight high-risk system categories on board vessels:

1. Bridge systems

2. Cargo handling and management systems

3. Propulsion and machinery management and power control systems

4. Access control systems

5. Passenger servicing and management systems

6. Passenger-facing public networks

7. Administrative and crew welfare systems

8. Communication systems[224]

A cyberattack on the IMO's own IT infrastructure in 2020 revealed institutional vulnerabilities.[225] Similarly, the U.S. Maritime Administration issued GPS interference

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219 Int'l Chamber of Shipping [ICS], Cyber Security: Guidance for Ship Operators on the International Maritime Organization Guidelines on Maritime Cyber Risk Management (2021).
220 IMO, MSC-FAL.1/Circ.3: Guidelines on Maritime Cyber Risk Management (2021).
221 Erik Rosaeg, Cybersecurity and the Law of the Sea, 47 Mar. Pol'y & Mgmt. 65, 77–78 (2020).
222 UNCTAD, Review of Maritime Transport 2021, U.N. Doc. UNCTAD/RMT/2021 (2021).
223 Astaara & BPA, supra note 38.
224 IMO, *MSC.428(98): Maritime Cyber Risk Management in Safety Management Systems* (2017).
225 IMO, *Press Briefing 32: IMO's IT Systems Attacked*, Sept. 30, 2020.

advisories, prompting the U.S. Coast Guard's NAVCEN to establish a cyber-reporting platform.[226] These developments highlight both the borderless nature of cyber threats and the urgent need for institutional reform.

3.5.4. Strategic Recommendations

To improve resilience, States and industry stakeholders should:

- Enact binding cybersecurity standards through IMO or regional agreements;
- Require cybersecurity certification and periodic audits for MASS operators;
- Mandate forensic logging and real-time threat detection systems;
- Encourage integration of maritime authorities into cybercrime response frameworks to ensure operational relevance.

Cybersecurity must be seen as a core component of operational safety and legal compliance for autonomous shipping, requiring harmonized global regulation, technological safeguards, and institutional coordination.

3.5.5. Cyber threats risk mitigation

Effective cybersecurity in maritime operations—particularly for Maritime Autonomous Surface Ships (MASS)—requires a multi-layered approach encompassing human factors, procedural rigor, and technological safeguards. Given that vulnerabilities often arise from non-technical weaknesses such as poor awareness or operational oversight, a holistic strategy is essential.

A. People: Building a Cyber-Aware Workforce

- Training and Awareness: All personnel—not just IT staff—must be trained to identify threats such as phishing, social engineering, or unauthorized access attempts. Routine drills and updated training modules can help maintain cyber vigilance.
- Email and Media Hygiene: Crew should engage only with verified communications and avoid interacting with suspicious files or links. Use of

[226] U.S. Coast Guard Navigation Center (NAVCEN), *GPS Interference Reporting and Awareness Platform*, https://www.navcen.uscg.gov.

personal USBs and devices should be strictly limited or prohibited on operational systems.

- Incident Reporting: A culture of proactive reporting should be fostered, with clear channels to report anomalies for rapid response.
- Emergency Protocols: Personnel must be trained in fallback procedures for operational technology (OT) disruptions, including manual overrides and system redundancy awareness.

B. Processes: Embedding Security into Operations

- System Updates and Backups: Regularly scheduled, secure software updates and encrypted backups are essential for maintaining operational resilience.
- Access Controls and Password Hygiene: Strong password policies and role-based access systems should be mandatory. Default credentials must be changed and administrative rights carefully managed.
- Software Whitelisting and Media Controls: Only verified programs should be installable on ship systems. All removable media must be pre-approved, scanned, and logged.
- Secure Communication Protocols: Sensitive operations should be conducted through encrypted, designated channels with a strict separation between personal and professional communications.
- Incident Response Plans: Organizations must establish clear cyber incident protocols—including system isolation, forensic investigation, and lessons-learned reporting—to reduce impact and ensure recovery.

C. Technology: Securing Maritime Digital Infrastructure

- Modernization of Legacy Systems: Outdated, unsupported hardware must be systematically phased out and replaced with encrypted and resilient alternatives.
- Deployment of Security Tools: Systems must include firewalls, antivirus programs, intrusion detection systems (IDS), and content filters to provide layered defense.

- User Authentication and Network Segmentation: Strong authentication protocols (e.g., MFA) and network segmentation can restrict intrusions and limit lateral threat movement.
- Monitoring and Audit: Continuous monitoring through functional testing, red-teaming, and security audits is essential for identifying and patching vulnerabilities in real time.

This tripartite framework acknowledges that crews are not cybersecurity experts, and the key to cyber resilience lies in building awareness, simplifying protocols, and ensuring system design does not overly depend on human perfection. In the context of MASS, this framework becomes even more critical—where remote operators or autonomous agents replace traditional shipboard roles, cyber preparedness must be engineered from the ground up to support both safety and legal accountability in line with emerging IMO and industry standards.

3.5.2. Marine Cybersecurity and International Conventions

The increasing reliance on digital technologies and automated systems in maritime operations has exposed critical gaps in existing international legal frameworks. Despite the centrality of cybersecurity to navigational safety, efficiency, and environmental protection, most foundational maritime treaties do not expressly address cyber threats. This omission reflects their pre-digital origin and underscores the urgent need for legal modernization in the face of evolving cyber risks.

Outdated Treaty Architecture

Key instruments such as the United Nations Convention on the Law of the Sea (UNCLOS), the International Convention for the Safety of Life at Sea (SOLAS), and the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) form the backbone of global maritime law.[227] These conventions establish rules on ship safety, equipment, communication, and crew competency. However, they predate the digital age and thus lack specific provisions for addressing cyberattacks, autonomous systems, or remote-control vulnerabilities. For instance, Article 94 of UNCLOS requires flag States to exercise effective jurisdiction and control over ships in matters of safety, navigation, and environmental protection.[228] While comprehensive

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[227] UNCLOS, supra note 6 arts. 94–97; SOLAS, supra note 7 ch. V; COLREGS, supra note 9
[228] UNCLOS, supra note 6, art. 94(4)

in scope, it does not mention cybersecurity. Similarly, SOLAS Chapter V on the "Safety of Navigation" mandates standards for navigational equipment, communication protocols, and reporting hazards—but fails to anticipate risks from cyber-manipulated systems.[229] The ISPS Code, introduced after 9/11 to enhance maritime security, focuses on physical threats like piracy and terrorism but does not include obligations to protect ships and ports from cyber intrusion.[230] These limitations collectively result in a regulatory vacuum, especially as cyberattacks increasingly target navigation, propulsion, and cargo handling systems.

Soft Law and Emerging Standards

Recognizing this gap, the International Maritime Organization (IMO) adopted Resolution MSC.428(98) in 2017, urging member States to integrate cyber risk management into existing safety management systems (SMS) by January 1, 2021.[231] The resolution applies through the International Safety Management (ISM) Code, thereby attaching cyber risk obligations to existing operational protocols. However, it remains non-binding and does not establish uniform global enforcement standards. Supporting instruments such as IMO Circular MSC-FAL.1/Circ.3, the BIMCO Cybersecurity Guidelines, and the IACS Recommendation on Cyber Resilience provide technical guidance, but rely on voluntary compliance.[232] These soft law instruments outline recommended practices such as risk identification, access control, threat detection, and post-incident recovery—elements essential to any effective cybersecurity framework.

Implementation and Industry Response

Despite the IMO's efforts, implementation across member States and private operators remains inconsistent. Ships calling at foreign ports may face increased scrutiny and contractual penalties for failing to meet cybersecurity expectations.[233] Non-compliant vessels risk charter refusals, insurance complications, and reputational damage,

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[229] SOLAS, supra note 7, ch. V, regs. 11–13.
[230] Int'l Ship and Port Facility Security Code, adopted by IMO Resolution 2, Dec. 12, 2002 [ISPS Code]
[231] Int'l Mar. Org. [IMO], *Maritime Cyber Risk Management in Safety Management Systems*, IMO Res. MSC.428(98), MSC 98/23/Add.1 (June 16, 2017).
[232] IMO, *MSC-FAL.1/Circ.3: Guidelines on Maritime Cyber Risk Management* (2021); Baltic and Int'l Mar. Council [BIMCO], *Guidelines on Cyber Security Onboard Ships* (4th ed. 2020); Int'l Ass'n of Classification Societies [IACS], *Recommendation on Cyber Resilience (Rec. 166)* (Apr. 2020).
[233] Erik Rosaeg, *Cybersecurity and the Law of the Sea*, 47 Mar. Pol'y & Mgmt. 65, 78 (2020).

especially in the aftermath of cyber incidents.[234]The growing adoption of electronic navigation systems, ship-to-shore data exchanges, and remote monitoring technologies makes these risks more acute. Autonomous vessels—particularly MASS operating under Degrees 3 and 4 of IMO classification—further complicate compliance. These ships may lack onboard crew or conventional command structures, rendering traditional concepts of "master," "crew," and human oversight obsolete. The current legal framework does not adequately define who bears responsibility for cyber resilience in the absence of a physical captain.[235]

Toward Binding International Regulation

To bridge this regulatory gap, scholars and industry groups have proposed:

- Amendments to UNCLOS and SOLAS to explicitly include cyber threats;
- A standalone international convention on maritime cybersecurity, potentially modeled on the Budapest Convention on Cybercrime or as a sector-specific instrument under IMO auspices;
- Clarification of the legal status of AI systems and remote operators, including liability distribution and response duties;
- Creation of a specialized judicial mechanism or cyber incident tribunal under UNCLOS or the International Tribunal for the Law of the Sea (ITLOS).[236]

Collaborative efforts by the Comité Maritime International (CMI), the International Association of Ports and Harbors (IAPH), and the International Association of Classification Societies (IACS) continue to promote technical harmonization, but legal adaptation remains slow. Without binding norms, international maritime cybersecurity remains a fragmented domain reliant on soft law, national legislation, and contractual safeguards.

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[234] Astaara Company Ltd. & British Ports Ass'n, *The Risk of Cybercrime to Maritime Infrastructure* (2020).
[235] Henrik Ringbom, *Regulating Autonomous Ships: Concepts, Challenges and Precedents*, 50 Ocean Dev. & Int'l L. 141, 160–62 (2019).
[236] U.N. Off. on Drugs & Crime, *Comprehensive Study on Cybercrime*, U.N. Doc. CTOC/COP/2013/3 (Feb. 2013); see also Comité Maritime Int'l [CMI], *Working Group on Cybercrime in Shipping*, www.comitemaritime.org

3.5.3. Cybersecurity in Autonomous Vessels

This section examines the cybersecurity challenges emerging alongside advancements in maritime technology, with particular emphasis on the rise of autonomous and unmanned vessels. As the industry moves toward greater automation, it becomes increasingly important to assess the cyber vulnerabilities inherent in these vessels. The growing concern within the cybersecurity research community stems from parallels drawn with other unmanned systems such as drones and autonomous land vehicles which have already demonstrated multiple exploitable attack surfaces. These can be targeted by malicious actors to carry out unauthorized intrusions, data breaches, and system manipulation[237]. In general, autonomous ships can be broadly categorized into two groups: Remotely Operated Vessels and Autonomously Operated Vessels.

- **Remotely Operated Vessels:** Remotely operated ships, though not fully autonomous, function with minimal onboard crew and depend heavily on advanced sensor arrays and algorithmic decision-making for accurate navigation through international waters. These vessels are directed by shore-based control centers, requiring continuous, real-time communication between the vessel and its remote operators. However, this high level of interconnectivity exposes a broad range of cyber vulnerabilities. Key attack surfaces include sensor systems, remote control interfaces, and the communication channels that facilitate data exchange. The bidirectional flow of information from ship to shore and vice versa raises serious data integrity and confidentiality concerns, making these systems attractive targets for cybercriminals seeking to intercept, alter, or manipulate critical operational data.

- **Autonomously Operated Vessels:** Although autonomous ships eliminate certain traditional cybersecurity vulnerabilities such as those stemming from human error or insider threats they remain exposed to a distinct set of cyber risks. A major concern is the threat of GPS spoofing, which can mislead navigation systems and redirect vessels off course. The communication links that enable data exchange between onboard systems and shore-based

[237] M. A. B. Farah, E. Ukwandu, H. Hindy, D. Brosset, M. Bures, I. Andonovic, X. Bellekens, Cyber Security in the Maritime Industry: A Systematic Survey of Recent Advances and Future Trends in Information, 2022.

infrastructure represent another significant attack surface. Exploiting these connections could lead to severe consequences, including collisions, loss of life, environmental disasters, and interruption of global shipping lanes. The vulnerability of these vessels is amplified by their reliance on interconnected devices and cloud-based systems. Weaknesses such as poor cryptographic key management, unsecured network interfaces, and inadequate safeguards in cloud data transmission further heighten the risk. The bidirectional nature of these communication flows where data is both retrieved from and stored in cloud environments creates additional entry points for cyber threats, making it imperative to design robust cyber-resilience strategies for autonomous maritime technologies[238].

The maritime sector stands to gain substantial advantages through the continued adoption of digital technologies. By shifting from traditional analog practices to data-driven systems, the industry can streamline operations such as cargo handling, procurement, and logistics, while fostering efficiency, safety, innovation, and environmental sustainability. Digital transformation also offers a pathway to gaining a competitive edge in an increasingly globalized and fast-paced marketplace. This digital evolution is powered by emerging technologies including blockchain, Big Data analytics, real-time monitoring systems, artificial intelligence (AI), robotics, autonomous vessels, networked communication platforms, virtual reality, and the Internet of Things (IoT). To accelerate this transformation, it is crucial for stakeholders to collaborate and share knowledge, enabling the development of new workflows, enhanced customer engagement, and more responsive service delivery.

The digitalization journey is typically understood in three progressive phases:

1. Optimization – Improving existing operations using digital tools.
2. Extension – Expanding digital integration across supply chains and service providers.
3. Transformation – Redesigning business models and operational strategies around digital capabilities.

[238] M. A. B. Farah, E. Ukwandu, H. Hindy, D. Brosset, M. Bures, I. Andonovic, X. Bellekens, Cyber Security in the Maritime Industry: A Systematic Survey of Recent Advances and Future Trends in Information, 2022, pp. 23-24.

Each phase introduces its own set of challenges, including the need for adequate funding, infrastructure development, and careful attention to cybersecurity risks that emerge with increased connectivity and data dependency.

In particular, Big Data and AI are driving new research directions in the maritime industry. These include:

- Enhancing maritime transport systems and port community infrastructure
- Leveraging AIS (Automatic Identification System) data for surveillance and sustainability monitoring
- Optimizing energy consumption onboard vessels
- Implementing predictive analytics for maintenance, navigation, and vessel performance

These technologies are essential not only for managing digitalization challenges but also for supporting real-time decision-making and improving safety outcomes. Furthermore, robotics is expected to play a pivotal role, especially in executing complex operational tasks aboard unmanned or autonomous vessels, where human intervention is minimal or absent[239].

3.6. Insurance and Risk Management Challenges

Maritime insurance encompasses various types of coverage, including Hull and Machinery (H&M) insurance for physical damage and Protection and Indemnity (P&I) insurance for third-party liabilities. Traditionally, these policies are structured around manned operations. However, the emergence of unmanned and autonomous ships introduces novel risk profiles that challenge existing insurance norms. H&M policies often include a "3/4ths Collision Liability clause," which makes shipowners responsible for a quarter of collision liability to encourage navigational prudence.[240] The remainder may be covered by extending hull insurance or supplementing it with P&I coverage. P&I clubs offer broader protection for environmental pollution, cargo damage, salvage, collision with fixed structures, and personal injury claims.

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[239] M. A. B. Farah, E. Ukwandu, H. Hindy, D. Brosset, M. Bures, I. Andonovic, X. Bellekens, Cyber Security in the Maritime Industry: A Systematic Survey of Recent Advances and Future Trends in Information, 2022

[240] See The Institute Time Clauses – Hulls (1/10/83), cl. 6; Marine Insurance Act 1906, 6 Edw. 7 c.41, & 55

Autonomous shipping reduces the relevance of crew-related liabilities mandated under the Maritime Labour Convention (MLC), 2006, such as repatriation or unpaid wage coverage.[241] However, this shift introduces new risks, notably cyber threats and product liability related to onboard software and remote operation systems. Insurance for piracy (e.g., Kidnap and Ransom [K&R] policies) and lender protections (Mortgagees Interest Insurance) are evolving, but cyber threats remain underinsured. The Institute Cyber Attack Exclusion Clause CL380 expressly excludes cyberattacks from standard marine insurance policies, widening the protection gap.[242] Encouragingly, P&I clubs like Gard, NorthStandard, and the Shipowners' Club have expressed readiness to craft insurance solutions for autonomous vessels.[243] Flexibility exists, including discretionary waivers of club rules, but the lack of actuarial data on MASS hinders premium setting and risk modeling.

As technology advances, insurance frameworks must adapt. Key reform areas include:

- Integration of cyber insurance within marine coverage;
- Expansion of product liability policies for system designers and software providers;
- Frameworks for remote operation failures and automation-specific exposures.

Without such adaptation, current insurance regimes risk becoming obsolete in the face of a transforming maritime landscape.

3.6.1. Insurance And Cybersecurity

As outlined in the preceding sections, cybersecurity threats are rapidly escalating within the maritime domain, creating new vulnerabilities across increasingly digitalized and automated systems. The advancement of automation and autonomy in shipping is expected to significantly amplify the risk of cyberattacks, particularly targeting critical shipboard systems. To counter these evolving risks, not only will cyber defense technologies need to become more robust and adaptive, but the insurance industry must also evolve to offer comprehensive and responsive coverage for cyber incidents. In this

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241 Maritime Labour Convention (MLC), 2006, Reg. 2.5; Standard A2.5.2 (as amended 2014).
242 Institute Cyber Attack Exclusion Clause CL380 (Nov. 2003).
243 Gard, *Autonomous Shipping and Marine Insurance: Practical Insights*, Gard Insight Blog (2020); NorthStandard, *Technology and Liability in Future Marine Risks* (2022); Shipowners' Club, *Insuring the Future of Unmanned Vessels* (2021).

regard, Protection and Indemnity (P&I) clubs are expected to play a pivotal role in shaping the insurance response to maritime cybersecurity. Despite the growing concern, the issue of cyber insurance coverage for autonomous ships remains largely unexplored. Therefore, it becomes essential to evaluate how major P&I clubs are currently addressing cyber risks in the context of traditional, manned vessels, as a reference point for potential future models applicable to autonomous ships. Given the transformative nature of autonomous maritime technology, the insurance sector—like many others—must adapt to the emerging realities of the digital era. The inevitability of these changes requires insurers to reassess risk models, redefine liability standards, and develop tailored coverage frameworks that align with the complex cyber threat landscape.

To understand the current state of readiness, an examination of three leading P&I clubs was conducted:

1. NorthStandard – a new entity formed in February 2023 through the merger of The North of England Protecting and Indemnity Association Limited (North) and The Standard Club.
2. Gard – one of the largest and most influential mutual marine insurers globally.
3. West P&I – a key player in the international P&I insurance market with a diverse global portfolio.

This analysis aims to assess the initiatives and responses undertaken by these institutions concerning cybersecurity coverage, and to evaluate their readiness to extend protection to autonomous and digitally-integrated vessels in the near future.

Northstandard club

The club's rules do not contain an explicit exclusion for cyber-related incidents, meaning that Protection and Indemnity (P&I) liabilities resulting from such events are generally covered under standard policy terms. However, this coverage may be limited or excluded when the war risks exclusion clause is triggered. For instance, if a cyberattack causes the failure of a vessel's navigational or mechanical systems, leading to third-party liabilities, standard P&I insurance would typically respond. However, if the event is classified as an act of terrorism or war, it falls under the excluded categories in the club's rules. In cases where there is uncertainty or dispute regarding whether an act qualifies as terrorism, the final determination lies with the club's board. If a cyberattack is ultimately deemed an act of terrorism or a war-related risk, the club's P&I war risks cover may still apply—but only in excess of any primary war risks coverage already held by the shipowner. An important limitation arises if the damage results from a computer virus, in which case coverage is restricted. In such scenarios, shipowners may seek limited protection under clauses related to biochemical risk inclusion, which can extend to certain forms of cyber-induced harm.

An essential condition of insurance coverage with the club is that all vessels must remain in full compliance with statutory obligations, including the validity of certificates issued by the ship's flag state. Notably, Rule 15.1 specifically references compliance with the International Safety Management (ISM) Code, which, since January 1, 2021, includes cybersecurity provisions. Given the increasing relevance of cyber risks, it is critical that shipowners can demonstrate proactive efforts to manage cybersecurity threats in alignment with the ISM Code. This becomes particularly important in disputes where a claim may be challenged on the basis of inadequate cyber preparedness. However, compliance standards may vary by flag state, especially in how Document of Compliance (DOC) and Safety Management Certificate (SMC) audits are conducted. As such, individual P&I clubs may independently assess cyber risk exposure, often requesting evidence of compliance and best practices—such as adherence to the BIMCO Guidelines on Cyber Security Onboard Ships. Claims are evaluated on a case-by-case basis, and the availability of coverage will depend heavily on the specific facts and circumstances of each incident. It is also important to note that not all cyber-related losses fall within the scope of P&I coverage, especially where no third-party liability is involved. For instance, financial losses arising from ransomware attacks, data breaches, or expenses related to system repairs, regulatory fines, or legal proceedings may fall outside the core coverage and potentially be addressed under Freight, Demurrage and Defence (FD&D) insurance instead. Ultimately, a thorough risk assessment is essential to identify potential insurance gaps and ensure that coverage adequately reflects the growing spectrum of cyber threats faced by modern shipping operations[244].

[244] A. Arora, E. Antoniadou, "Maritime Cyber Risk Management Guidelines", The Northstandard Club, vailable at: https://www.standard club.com/fileadmin/uploads/standardclub/Documents/Import/publications/loss-prevention-industry expertise-handouts/3365323-sc_ie_cyber_risks_20201117_final.pdf

West P&I

At present, standard Protection and Indemnity (P&I) insurance policies do not explicitly exclude cyber-related incidents. However, coverage is conditional upon the member's conduct. Ship owners and operators must avoid actions that could be deemed imprudent, unsafe, hazardous, or improper, a standard that also applies to their management of cyber risks. Failure to exercise due diligence in cybersecurity preparedness could potentially jeopardize insurance coverage, even in the absence of a specific cyber exclusion clause.

War & Terrorism

There is growing concern within the maritime insurance sector over cyber risks that may fall under the category of war risks. The capabilities of terrorist groups, ideologically motivated hackers, and even state-sponsored actors have become increasingly advanced, raising alarms about potential interference with critical navigation systems, such as GPS. In general, Protection and Indemnity (P&I) clubs do not act as the primary underwriters for war risk-related liabilities. Instead, war P&I coverage is typically offered as a supplemental policy in conjunction with a vessel's hull war risk insurance. As such, liabilities arising from cyberattacks on a vessel may trigger the war risks exclusion in standard P&I policies, which excludes coverage for "any hostile act by or against a belligerent power" or "any act of terrorism."[245] Whether a particular cyber incident qualifies as an "act of terrorism" often hinges on the intent and motivation of the individual or entity responsible. Under the UK Terrorism Act 2000[246], terrorism is defined as any act or threat intended to advance political, religious, racial, or ideological objectives. This includes actions designed to seriously disrupt or interfere with electronic systems, making many forms of cyberattacks potentially fall within this legal definition. While International Group (IG) P&I clubs do offer a P&I

[245] https://www.westpandi.com/news-and-resources/news/archive/p-i-cover-and-cyber-risk/

[246] Article 1 "Terrorism: interpretation." states that: 1.In this Act "terrorism" means the use or threat of action where— (a)the action falls within subsection (2), (b)the use or threat is designed to influence the government [F1 or an international governmental organisation] or to intimidate the public or a section of the public, and (c)the use or threat is made for the purpose of advancing a political, religious [F2, racial] or ideological cause. 2. Action falls within this subsection if it— (a)involves serious violence against a person, (b)involves serious damage to property, (c)endangers a person's life, other than that of the person committing the action, (d)creates a serious risk to the health or safety of the public or a section of the public, or (e)is designed seriously to interfere with or seriously to disrupt an electronic system. https://www.legislation.gov.uk/ukpga/2000/11/section/1

war risks extension of up to US$500 million[247], there are important limitations. Most notably, this coverage excludes losses resulting from the use or operation of a computer virus as a means of causing harm. This exclusion mirrors the widely adopted cyber exclusion clause CL380[248], often found in primary war risk insurance policies. This creates a significant coverage gap in scenarios where a cyberattack is classified as an act of terrorism involving a computer virus, a ship owner may find themselves without effective P&I insurance protection. As cyber threats continue to evolve in complexity and scale, clarifying and expanding insurance coverage to address these new risks becomes increasingly urgent.

Future

At present, P&I club coverage does not explicitly define its position on cyber risks, except in relation to war risks, where exclusions may apply. Cyber liabilities are neither clearly included nor excluded in most policy wordings, creating what is often referred to as "silent cyber" exposure, a term describing the uncertain or ambiguous treatment of cyber risks in traditional insurance policies. In response to growing concerns, the Prudential Regulation Authority (PRA), a regulatory arm of the Bank of England, issued a directive on January 30, 2019, calling upon Lloyd's of London and the broader insurance industry to address this ambiguity. As a result, Lloyd's mandated that all insurance policies, including first-party property damage coverage, must clearly specify their stance on cyber risks either through explicit exclusions or affirmative coverage provisions, effective from January 1, 2020. In line with this regulatory shift, P&I clubs within the International Group (IG) have committed to ensuring that their members receive comprehensive and transparent coverage, while continuing to comply with the IG Pooling Agreement[249]. Generally, standard P&I policies issued by IG clubs do not

[247] https://www.westpandi.com/news-and-resources/news/archive/p-i-cover-and-cyber-risk/

[248] INSTITUTE CYBER ATTACK EXCLUSION CLAUSE 1.1 Subject only to clause 1.2 below, in no case shall this insurance cover loss damage liability or expense directly or indirectly caused by or contributed to by or arising from the use or operation, as a means for inflicting harm, of any computer, computer system, computer software programme, malicious code, computer virus or process or any other electronic system. 1.2 Where this clause is endorsed on policies covering risks of war, civil war, revolution, rebellion, insurrection, or civil strife arising therefrom, or any hostile act by or against a belligerent power, or terrorism or any person acting from a political motive, Clause 1.1 shall not operate to exclude losses (which would otherwise be covered) arising from the use of any computer, computer system or computer software programme or any other electronic system in the launch and/ or guidance system and/or firing mechanism of any weapon or missile.

[249] According to igpandi.org: "Although the Group Clubs compete with each other for business, it is to the benefit of all shipowners insured by Group Clubs for the Clubs to pool their larger risks. Pooling is regulated by the annually renewed Pooling Agreement which defines the risks that can be pooled, those

exclude cyber risks when they arise from liabilities related to the operation of an entered vessel. The IG Pooling Agreement itself contains a specific clause affirming the inclusion of cyber risks, which is also honored by the group's reinsurance partners. These terms are routinely evaluated and updated ahead of each renewal cycle to reflect developments in risk exposure and insurance practice. Meanwhile, clubs remain committed to supporting their members by not only providing P&I coverage for cyber-related liabilities, but also offering guidance, risk assessment support, and insurance advice to help manage the evolving landscape of cyber exposure in maritime operations[250].

Gard

As maritime operations become increasingly reliant on digital technologies, Gard has developed a comprehensive cyber risk management strategy focused on protecting both Information Technology (IT) and Operational Technology (OT) systems. The club emphasizes the triad of technology, procedures, and personnel, recognizing that human error remains one of the most common cyber vulnerabilities.[251]

Recommendation 1: Integrated Cyber Risk Management

Gard supports the IMO's MSC-FAL.1/Circ.3 and the Guidelines on Cyber Security Onboard Ships, encouraging alignment with the ISM and ISPS Codes.[252] These frameworks promote integration of the five core cybersecurity principles:

- Identify critical assets and responsibilities;
- Protect systems with controls and redundancy;
- Detect anomalies quickly;
- Respond to incidents with continuity measures;

Recover through structured restoration planning.

Operators must clearly define cyber responsibilities, particularly in third-party management structures, and ensure contracts reflect data protection obligations under

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risks which are excluded from cover, and how covered losses are to be shared between the participating Clubs. The Pool provides a mechanism for sharing all claims in excess of US$ 10 million up to, currently, approximately US$ 8.9 billion." https://www.igpandi.org/group-agreements/

[250] https://www.westpandi.com/news-and-resources/news/archive/p-i-cover-and-cyber-risk/

[251] Gard, *Cyber Security: Understanding the Risk Onboard* (2021), https://www.gard.no/web/articles

[252] Int'l Mar. Org. [IMO], *Guidelines on Maritime Cyber Risk Management*, MSC-FAL.1/Circ.3 (2021); Baltic & Int'l Mar. Council [BIMCO], *Guidelines on Cyber Security Onboard Ships* (4th ed. 2020).

frameworks such as the EU GDPR and national cybersecurity legislation.[253] Coordination among stakeholders—port agents, authorities, vendors—is essential, given the complex digital interconnectivity of port calls.

Recommendation 2: System Design and Configuration

Gard highlights that cybersecurity must be built into vessel systems, not added as an afterthought. Many ships still operate with outdated software, weak access controls, poor segmentation, and excessive vendor access.[254] Remote-access vulnerabilities are particularly concerning, with shipboard systems like navigation, ballast, cargo handling, propulsion, and shutdown functions increasingly exposed via continuous internet connections. Gard advises thorough IT/OT risk assessments—including third-party integrations—to identify attack vectors and mitigate operational consequences across high-risk systems such as LNG emergency shutoffs and cable-laying controls.

Recommendation 3: Human Factor and Training

The human element is the most persistent vulnerability in maritime cybersecurity. Despite increased digitalization, seafarer cyber training remains inconsistent. A 2018 Crew Connectivity Survey reported that most crew had not received structured cyber instruction.[255] To address this, Gard and DNV-GL launched a seafarer awareness campaign focused on practical behaviors rather than regulatory mandates. The campaign emphasizes safe digital practices, awareness of phishing, cautious USB usage, and improved password habits. It aims to translate technical controls into operational mindfulness. Gard has also warned of phishing scams exploiting global events like COVID-19, advising personnel to rely only on verified information, avoid sharing sensitive data via email, and immediately disable remote access after vendor servicing to reduce risk exposure.[256]

3.7 Conclusion

This chapter has explored the complex and evolving landscape of liability in the context of Maritime Autonomous Surface Ships (MASS). As automation and artificial intelligence increasingly displace traditional seafaring roles, conventional liability

[253] See Regulation (EU) 2016/679, General Data Protection Regulation, 2016 O.J. (L 119) 1.
[254] Gard, *Cybersecurity on Board – Practical Approaches to Complex Threats* (2022).
[255] FutureNautics, *Crew Connectivity 2018 Survey Report*, https://www.futurenautics.com
[256] Gard, *Phishing Emails and Cyber Risks During the COVID-19 Pandemic*, Gard Alerts (Apr. 2020).

frameworks rooted in fault-based negligence, command responsibility, and human oversight are proving inadequate. The legal presumption of a ship being under the charge of a master and crew no longer holds in the era of autonomous vessels, thereby demanding a structural rethinking of how accountability is assigned in maritime incidents.The discussion has highlighted the limitations of existing doctrines, including strict liability regimes and tort-based models, when applied to autonomous operations. The chapter also detailed the growing fragmentation of liability among multiple actors, from ship owners and software developers to remote operators and component manufacturers, each of whom plays a part in the functioning of MASS. In the absence of a coherent liability model, this multiparty ecosystem raises serious questions about causation, foreseeability, and enforceability. The exploration of product liability revealed further complications, particularly as the “product” in question, an AI or software-driven navigation system may evolve over time, making defect attribution and long-term liability difficult to establish. The chapter also examined the significant role of cybersecurity risks in shaping liability, with threats ranging from GPS spoofing to ransomware attacks, and emphasized the lack of robust legal instruments to deal with such digital vulnerabilities in maritime settings. The final sections addressed the profound implications for insurance and underwriting practices. Existing Protection & Indemnity (P&I) and Hull and Machinery (H&M) insurance models do not fully account for the risks posed by autonomous operations, especially where cyber threats or non-human actors are involved. Although some P&I clubs are beginning to adapt, the regulatory and contractual landscape remains in flux, with many uncertainties around coverage for digital incidents, AI malfunctions, and cross-border claims. In sum, the chapter demonstrates that autonomous shipping represents not merely a technological disruption but a foundational legal challenge to the maritime liability regime. MASS requires the development of integrated liability models, updated insurance instruments, cybersecurity protocols, and revised legal definitions that reflect the realities of machine-led operations at sea. Accordingly, the next chapter will undertake a comparative and regulatory analysis, examining how different jurisdictions are responding to the emergence of autonomous vessels. It will explore legislative innovations, pilot programs, and policy frameworks in various legal systems including the European Union, Norway, Japan, Singapore, and others with a view to identifying best practices, regulatory gaps, and potential pathways for international harmonization.

CHAPTER 4

COMPARATIVE AND REGULATORY ANALYSIS

4.1. Introduction

As Maritime Autonomous Surface Ships (MASS) advance from concept to operational reality, States and international institutions have begun crafting legal and regulatory responses to address their unique risks and operational complexities. However, these responses vary significantly in scope, structure, and sophistication, reflecting both differing levels of technological maturity and divergent legal traditions. The absence of a globally harmonized regulatory framework raises challenges for cross-border navigation, liability determination, port access, and flag State compliance. This chapter undertakes a comparative and regulatory analysis of the current legal landscape for autonomous ships. It explores how jurisdictions such as Norway, the European Union, Japan, Singapore, the United Kingdom, and the United States are addressing the regulation of MASS, either through dedicated legislation, pilot programs, classification standards, or soft law instruments. It also evaluates the evolving role of international organizations, notably the International Maritime Organization (IMO), in laying the groundwork for uniform standards.

By examining these developments, the chapter aims to:

- Identify leading legal models and policy innovations,
- Highlight persistent regulatory gaps and inconsistencies,
- Assess the prospects for international harmonization, and
- Provide recommendations for the formulation of a robust and forward-looking regulatory framework for autonomous maritime operations.

4.2. Norway: Legal Adaptation through Real-World Testing

Among the jurisdictions experimenting with Maritime Autonomous Surface Ships (MASS), Norway stands out as a global front-runner, combining technological ambition with flexible legal adaptation. With its robust maritime heritage, innovation-driven policy environment, and close cooperation between government, industry, and classification bodies, Norway has transformed itself into a living laboratory for autonomous shipping. The country's approach centers not on premature legislative overhaul, but on regulated experimentation, where the legal framework is allowed to evolve incrementally alongside technical advancements[257].

4.2.1. The Yara Birkeland: A Case Study in Applied Innovation

A pivotal development in Norway's autonomous maritime initiative is the Yara Birkeland, a fully electric, zero-emissions container ship designed to operate with increasing levels of autonomy, from manned operations to remote control and eventually to full autonomy. Developed by Yara International in collaboration with Kongsberg Maritime, the project has received global attention not only for its sustainability goals but also for testing the legal feasibility of deploying autonomous ships within regulated maritime zones[258].The ship's trial operations are taking place within the Norwegian Maritime Authority's (NMA) designated test area in the Oslofjord. These test areas are authorized under Norwegian law and enable exemptions from certain manning and navigational requirements, provided that the operational risks are assessed and mitigated through robust safety cases. The legal flexibility provided by the NMA ensures that operators can deviate from standard SOLAS or STCW-based rules without violating Norway's international obligations, as long as equivalent safety and oversight are maintained[259].

4.1.2. Regulatory Framework and Adaptive Oversight

Norway has not enacted a standalone legal instrument dedicated solely to autonomous ships. Instead, it has relied on a case-by-case regulatory adjustment model, implemented through the powers of the NMA under the Norwegian Ship Safety and Security Act[260]. This Act allows the NMA to grant exemptions and to set specific operational conditions in cases where conventional requirements do not align with emerging technologies.

The core elements of Norway's adaptive legal model include:

- Designated test zones where MASS may operate under alternative compliance frameworks;

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[257] Henrik Ringbom, *Regulating Autonomous Ships: Concepts, Challenges and Precedents*, 20 Ocean Y.B. 145, 149–50 (2020).

[258] DNV, *Yara Birkeland: The World's First Autonomous and Zero-Emission Container Ship*, https://www.dnv.com

[259] Norwegian Maritime Authority, Testing of Autonomous Ships in Norwegian Waters, NMA Circular RS 12-2018 (June 2018).

[260] Lov om skipssikkerhet [Ship Safety and Security Act], Act No. 9 of 16 Feb. 2007 (Nor.).

- Requirements for safety cases, including risk analyses, incident response plans, and cybersecurity assessments;
- Close consultation with classification societies, particularly DNV (Det Norske Veritas), which has been instrumental in creating autonomy classifications such as "Autonomous Notation" and issuing technical standards for MASS certification;
- Engagement with international stakeholders, including the IMO, to ensure alignment with the broader maritime safety and environmental regime[261].

This regulatory posture reflects Norway's principle of functional equivalence: rather than rewrite all applicable maritime laws, regulators permit deviations when operators can prove that the safety and reliability of autonomous systems match or exceed those of crewed operations[262].

4.1.3. Industry and Research Collaboration

Norway's approach to regulating autonomous ships is also marked by strong public–private collaboration. Research institutions such as SINTEF Ocean, together with maritime industry actors like Kongsberg and Massterly (a joint venture of Wilhelmsen and Kongsberg), contribute significantly to both the technical feasibility and regulatory design of autonomous systems[263]. One of the key advantages of this ecosystem is the real-time feedback loop it creates between legal development and operational experience. Regulators observe actual operations under monitored conditions, while developers adjust their systems based on compliance requirements. This dynamic interplay enables gradual regulatory learning, which may ultimately inform permanent reforms at the national and international levels[264].

4.1.4. Norway's Influence on Global Standard-Setting

Although Norway has not yet introduced permanent legislative reforms for autonomous shipping, its practical and pragmatic approach has had a disproportionate influence on international standard-setting. Norway actively contributes to the IMO's Maritime Safety Committee (MSC) and Legal Committee (LEG), including the development of

[261] DNV, *DNV Guidelines for Autonomous and Remotely Operated Ships*, DNVGL-CG-0264 (2022).
[262] Ringbom, supra note 257, at 151–52.
[263] Massterly, Enabling Autonomous Ships, https://www.massterly.com.
[264] Henning Oltmann, *Autonomous Shipping in Norway: The Road from Test Areas to Regulation*, 11 J. Mar. Tech. & Pol'y 31, 35–36 (2023).

the IMO's Regulatory Scoping Exercise and the upcoming MASS Code[265]. Furthermore, DNV's classification notations and safety standards are increasingly referenced as de facto industry benchmarks for certifying MASS. For example, the "DNV MASS Level" scheme categorizes vessels into five levels of autonomy, from manual to fully autonomous, and provides corresponding certification pathways[266]. These models offer a structured way to operationalize autonomy within a risk-managed legal framework, without the need for radical legislative reengineering.

4.1.5. Strengths and Limitations

Norway's regulatory strategy offers several advantages:

- It encourages technological innovation without legal paralysis;
- It preserves international compliance by relying on functional equivalence and safety validation;
- It enhances cross-sector coordination among regulators, developers, insurers, and classification societies;
- It generates empirical data and regulatory precedent that other jurisdictions can emulate.

However, the approach is not without its limitations:

- The lack of binding legislation may lead to legal uncertainty when moving from pilot phases to commercial operations;
- Case-by-case regulation is resource-intensive and may not be scalable as the number of MASS increases;
- The temporary and localized nature of test zones limits applicability in broader, international waters[267].

4.2 The European Union's Legal and Policy Response

The European Union (EU) has positioned itself as a key player in the global discourse on maritime digitalization and automation. Unlike Norway's experimental, case-by-

[265] Int'l Mar. Org., Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), IMO Doc. MSC 103/5/2 (May 2021).
[266] DNV, DNV Recommended Practice: Assurance of Autonomous Maritime Systems, DNVGL-RP-0496 (2023).
[267] Ringbom, supra note 257, at 153.

case model, the EU's approach reflects its regulatory tradition of harmonization, integration, and legislative standard-setting across Member States. The EU strategy combines legal readiness, research investment, and regulatory foresight, making it a major force in shaping future governance of Maritime Autonomous Surface Ships (MASS) both regionally and globally[268].

4.2.1. Strategic Vision and Policy Integration

The EU's policy on maritime automation is framed within its broader Smart and Sustainable Mobility Strategy, a key component of the European Green Deal. The European Commission recognizes autonomous and remotely operated vessels as critical to achieving decarbonization, digital transformation, and maritime safety[269].

These policy goals are coordinated through:

- The **Digital Transport and Logistics Forum (DTLF)**;
- The **European Maritime Safety Agency (EMSA)**;
- Funding mechanisms under **Horizon Europe** and the **Connecting Europe Facility (CEF)**.

The 2020 strategy underscores the need for a coherent regulatory framework to address legal uncertainties and harmonize rules for MASS across the internal market[270].

4.2.2. Regulatory Framework and EMSA's Role

The European Maritime Safety Agency (EMSA) has assumed a central role in facilitating the legal integration of autonomous shipping. In 2020, EMSA published its *Study on the Safe Implementation of Maritime Autonomous Surface Ships (MASS) in the EU*, which assessed the applicability of existing legal instruments such as UNCLOS, SOLAS, COLREGs, and EU secondary legislation to MASS[271].

Key EMSA recommendations included:

- Adopting a phased regulatory approach based on different degrees of autonomy;

[268] Henrik Ringbom, Autonomous Ships and the EU Regulatory Framework: Navigating Between Innovation and Fragmentation, 36 Int'l J. Mar. & Coast. L. 23, 25–26 (2021).
[269] European Commission, Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future, COM(2020) 789 final (Dec. 2020).
[270] Id. at 12–13.
[271] European Maritime Safety Agency (EMSA), *Study on the Safe Implementation of Maritime Autonomous Surface Ships (MASS) in the EU* (2020), https://www.emsa.europa.eu

- Clarifying the legal status of MASS within EU port access and navigation laws;
- Establishing EU-wide testing guidelines for MASS trials in national waters;
- Strengthening interoperability and cybersecurity standards for remote and autonomous operations[272].

EMSA also coordinates with the **European Union Agency for Cybersecurity (ENISA)** to address threats to digital infrastructure, including supply chain vulnerabilities and maritime control systems[273].

4.2.3. MASS in EU Legal Instruments and Funding Frameworks

While the EU has not enacted a binding regulation dedicated solely to MASS, it has employed **soft** law and economic instruments to steer legal and operational harmonisation. Notable regulatory developments include:

- The Maritime Single Window Regulation, which promotes digital interfaces for port and customs data flows[274].
- The Marine Equipment Directive, which governs technical standards and is being reviewed to address autonomous and AI-integrated systems[275].

Through Horizon Europe, CEF, and joint industry projects, the EU has funded several leading initiatives, including:

- **AUTOSHIP**, which develops and tests two autonomous cargo vessels for inland and short-sea shipping[276].
- **MOSES**, a project to enhance automation in short-sea shipping and terminal operations[277].

[272] Id. at 37–41.
[273] European Union Agency for Cybersecurity (ENISA), *Cyber Risk Management for Maritime Sector* (2021), https://www.enisa.europa.eu
[274] Regulation (EU) 2019/1239 of the European Parliament and of the Council of 20 June 2019 Establishing a European Maritime Single Window Environment, 2019 O.J. (L 198) 64.
[275] Directive 2014/90/EU of the European Parliament and of the Council of 23 July 2014 on Marine Equipment, 2014 O.J. (L 257) 146.
[276] European Commission, *AUTOSHIP – Autonomous Shipping Initiative for European Waters*, Horizon 2020 Project Information, https://cordis.europa.eu/project/id/815012
[277] European Commission, *MOSES – Automated Vessels and Port Logistics*, Horizon 2020, https://cordis.europa.eu/project/id/861678

- **MarTERA**, which funds transnational maritime technology projects focused on automation and sustainability[278].

4.2.4. Comparative Advantages and Limitations

The EU's approach offers key comparative advantages:

- It fosters regulatory harmonization across Member States, avoiding legal fragmentation;
- It embeds cybersecurity, environmental, and safety considerations into policy from the outset;
- It uses funding instruments strategically to align industrial innovation with legal development.

Yet, challenges remain:

- There is still no binding EU legislative framework specific to MASS, and domestic rules vary;
- The division of competences between the EU and Member States complicates unified enforcement;
- Many current legal instruments remain technology-neutral, lacking specific rules for MASS operations.

Debate is also ongoing regarding the applicability of the forthcoming EU Artificial Intelligence Act. Under the current draft, autonomous ships, depending on their safety-critical functions, could be categorized as "high-risk AI systems," thereby triggering strict requirements for human oversight, data transparency, and algorithmic accountability[279]. These programs not only foster innovation but also inform EU-level policy development through structured impact assessments and industry dialogue.

4.3. Japan's Proactive National Regulation and Smart Port Strategy

Japan, as one of the world's most influential maritime nations, has adopted a decisive and centralized approach toward the legal integration of Maritime Autonomous Surface Ships (MASS). Its strategy diverges from the experimentation-based regulatory

[278] MarTERA ERA-NET Cofund, *Project Portfolio*, https://www.martera.eu
[279] Proposal for a Regulation of the European Parliament and of the Council Laying Down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act), COM (2021) 206 final, arts. 6–9.

sandbox model seen in Norway and the multi-level governance system of the European Union. Instead, Japan embraces a model of **state-led legal codification**, coupled with extensive investment in smart port ecosystems and public–private research collaboration[280].

4.3.1. Government-Led Legislative and Administrative Reforms

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has led Japan's regulatory reforms by introducing legislation that directly authorizes the development and testing of MASS. In 2020, the Ship Safety Law was amended to permit demonstration voyages by autonomous vessels under defined legal safeguards[281].

Under this regime:

- MLIT grants special permits for remote and unmanned ship trials;
- Approved vessels must include data logging, obstacle detection, and manual override systems;
- Applicants are required to submit detailed risk mitigation plans and contingency protocols.

Japan's Autonomous Ship Development and Social Implementation Roadmap, published in 2022, further commits to enabling commercial MASS operations by 2025 and identifies specific regulatory milestones to support deployment[282].

4.3.2. MEGURI2040 and Demonstration Projects

The MEGURI2040 initiative, launched by The Nippon Foundation and administered by MLIT, is Japan's flagship program for MASS development. The initiative includes government-backed funding and regulatory alignment for full-scale autonomous vessel testing[283].

Key demonstration projects include:

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[280] Henrik Ringbom, *Regulating Autonomous Ships: Concepts, Challenges and Precedents*, 20 Ocean Y.B. 145, 155 (2020).
[281] Ship Safety Act (船舶安全法), Act No. 11 of 1933, as amended by Act No. 43 of 2020 (Japan).
[282] MLIT, *Roadmap for the Development and Social Implementation of Autonomous Ships* (June 2022), https://www.mlit.go.jp/maritime/content/001506524.pdf.
[283] The Nippon Foundation, *MEGURI2040 – Aiming for Autonomous Ships by 2040*, https://www.nippon-foundation.or.jp/en/what/projects/meguri

- The **Sakura**, a Ro-Ro ferry trialed by Shin Nihonkai Ferry, which achieved autonomous navigation and berthing with onboard crew backup;
- The **Suzaku**, a cargo ship trialed by Mitsubishi Shipbuilding and NYK Line, featuring AI-powered route optimization and collision-avoidance technology[284].

These projects are linked to a national certification scheme, allowing operational insights to be formally incorporated into Japan's regulatory pipeline.

4.3.3. Smart Ports as Legal and Technical Enablers

Japan's Smart Port Promotion Strategy integrates MASS readiness with broader logistics modernization. Through this initiative, MLIT works to upgrade port infrastructure with AI-based Vessel Traffic Management (VTM), 5G communications, and Internet-of-Things (IoT) networks[285].

Flagship smart ports include:

- **Yokohama**, where port authorities have piloted real-time berth monitoring and data-sharing with autonomous vessels;
- **Kobe**, which has integrated automated cargo cranes and digital twin simulations for traffic flow;
- **Tokyo**, serving as a regulatory lab for cyber risk simulations and autonomous docking validation.

These ports serve as practical extensions of the MASS testing environment, embedding vessel autonomy into the operational and regulatory framework of Japanese logistics systems.

4.3.4. Legal and Strategic Implications

Japan's approach provides several advantages:

- It enables enforceable MASS operation under binding national legislation, providing legal certainty;

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[284] Japan Maritime Daily, Suzaku Completes Autonomous Sea Trials, Mar. 8, 2023, https://www.jmd.co.jp/articles/38529.

[285] MLIT, Smart Port Concept and Future Strategy, Presentation at the Maritime Innovation Forum (Oct. 2022), https://www.mlit.go.jp/port/press/20221017_smartport.pdf.

- It incorporates port-side regulatory capacity, ensuring that land-based infrastructure supports sea-based autonomy;
- It is underpinned by a national digital strategy, making MASS part of Japan’s long-term technological and economic planning[286].

However, challenges remain:

- Japan’s unilateral standards may create interoperability issues in international waters;
- The legal treatment of AI decision-making under Japan’s Civil Code (particularly Articles 709 and 715 concerning tort and vicarious liability) remains underdeveloped and may need judicial clarification or legislative supplementation;[287]
- Coordination with IMO-level standards and flag State norms is still ongoing, raising potential issues for cross-border regulatory recognition.

Nonetheless, Japan’s combination of technological capability, legislative action, and infrastructure investment forms one of the most cohesive national strategies for the implementation of MASS and is likely to influence both regional practices and international legal discourse.

4.4. Singapore and the IMO’s Coordinated Regional Engagement Model

Singapore, an established global maritime hub, has emerged as a key stakeholder in the legal, operational, and technological development of Maritime Autonomous Surface Ships (MASS). Unlike jurisdictions that either emphasize national experimentation (e.g., Norway) or centralized legal reform (e.g., Japan), Singapore pursues a hybrid model that combines regulatory agility, international alignment, and strategic collaboration with the International Maritime Organization (IMO)[288]. Its efforts are grounded in legal innovation, digital port infrastructure, and global outreach, positioning Singapore not only as a leader in autonomous shipping governance but also as a facilitator of regional harmonization through coordinated engagement mechanisms

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[286] Cabinet Secretariat, *Japan’s Digital Agency and Maritime Transformation Strategy* (2021), https://www.digital.go.jp/assets/plan/strategy_en.pdf.
[287] Civil Code of Japan, Law No. 89 of 1896, arts. 709–715.
[288] Henrik Ringbom, *Autonomous Ships and the IMO Regulatory Framework*, 20 Ocean Y.B. 145, 153 (2020).

4.4.1. Legal and Regulatory Framework for MASS in Singapore

The Maritime and Port Authority of Singapore (MPA) has adopted a flexible **sandbox regulatory model**, operating under the Maritime and Port Authority of Singapore Act (Cap. 170A**)**, which empowers the agency to issue permits and operational directives[289]. MPA issues Port Marine Circulars to set out navigational protocols for MASS, including safety buffers, tug escort requirements, and real-time monitoring criteria. In 2021, MPA partnered with ST Engineering and the Singapore Institute of Technology (SIT) to launch the Autonomous Maritime Testbed (SMART), facilitating controlled MASS trials in port waters[290].

Key aspects of Singapore's approach include:

- Real-time remote monitoring requirements;
- Compliance with vessel registration and reporting standards;
- Integration of shore-based control centers;
- Coordination with class societies like Lloyd's Register to ensure compliance[291].

Singapore's Sea Transport Industry Transformation Map 2025 identifies autonomous shipping and smart port development as top national priorities, reinforcing regulatory support for MASS innovation[292].

4.4.2. Smart Port Strategy and Operational Readiness

Singapore's Tuas Port, scheduled to be fully operational by 2040, is a cornerstone of the nation's MASS-readiness strategy. The facility is being designed to include:

- Automated stacking cranes and container handling;
- A next-generation vessel traffic management system (VTMS);
- Seamless digital connectivity for unmanned vessels.

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[289] Maritime and Port Authority of Singapore Act, Cap. 170A, 1996 Rev. Ed. (Sing.).

[290] Maritime and Port Authority of Singapore, MPA Launches Autonomous Maritime Testbed, Press Release (June 23, 2021), https://www.mpa.gov.sg/web/portal/home/media-centre/news-releases.

[291] Lloyd's Register, Maritime Autonomous Surface Ships – Guidance for Assessment (2022), https://www.lr.org

[292] Singapore Ministry of Transport, Sea Transport Industry Transformation Map 2025, https://www.mot.gov.sg/docs/default-source/default-document-library/sea-transport-itm-2025.pdf.

MPA has deployed 5G maritime testbeds to enable high-bandwidth data transmission essential for remote vessel control and situational awareness[293].Digital clearance processes under the Maritime Single Window also support MASS operations, complying with FAL Convention amendments and enabling autonomous ships to transmit port call data autonomously[294].

4.4.3. Singapore's Role in IMO's Regional Model for MASS

Singapore's influence in shaping the international and regional regulatory environment for MASS extends beyond its domestic regulatory agility and infrastructure leadership. As a Council Member of the International Maritime Organization (IMO) and a recognized global maritime node, Singapore has actively contributed to both the Regulatory Scoping Exercise (RSE) and the broader efforts toward formulating a mandatory MASS Code. However, what sets Singapore apart is its role in regionalizing the IMO agenda, ensuring that Southeast Asian nations are not left behind in the transition to autonomous maritime technologies. One of the primary platforms for this regional engagement is the IMO–Singapore Maritime Autonomous Technology Workshop Series, first launched in 2021 and continuing through 2024. These workshops are jointly hosted by the IMO and the Maritime and Port Authority of Singapore (MPA), and bring together regulators, port authorities, legal experts, and technology developers from over 30 countries to explore the practical, legal, and safety dimensions of MASS implementation[295]. Key themes include:

- The legal status of remote operators and their alignment with STCW requirements;
- Port State control challenges in monitoring unmanned vessels;
- Flag State certification procedures for AI-driven navigation systems;
- Cybersecurity harmonization across maritime jurisdictions.

[293] Infocomm Media Development Authority (IMDA), *5G for Maritime Operations*, https://www.imda.gov.sg.

[294] International Maritime Organization, FAL Convention Amendments Mandate Maritime Single Window, IMO News (Jan. 2024), https://www.imo.org

[295] Int'l Mar. Org., Report of the IMO–Singapore Maritime Autonomous Technology Workshop 2022, MSC/Circ.1674 (Mar. 2023), https://www.imo.org/en/OurWork/Facilitation/Documents/MSC_Circ1674.pdf.

Singapore's regional leadership also extends to ReCAAP ISC (Regional Cooperation Agreement on Combating Piracy and Armed Robbery against Ships in Asia). ReCAAP, headquartered in Singapore, is a key platform for information-sharing and maritime security cooperation in Asia. While originally focused on conventional piracy threats, the organization has expanded its analytical purview to include autonomous vessel vulnerabilities, particularly concerning signal jamming, hijack via cyber intrusion, and legal ambiguity in responding to acts committed against uncrewed vessels[296]. Additionally, Singapore plays a leading role in ASEAN's maritime policy framework, particularly under the ASEAN Transport Strategic Plan 2016–2025 (Kuala Lumpur Transport Strategic Plan). Within ASEAN forums, Singapore advocates for the inclusion of digital maritime infrastructure and legal interoperability for autonomous operations, pushing for shared standards for MASS pilot programs, common data exchange protocols, and coordinated maritime cybersecurity responses[297]. Through these multilayered platforms, Singapore advances a regional model in which legal development, operational readiness, and institutional capacity-building move in tandem. This not only enhances ASEAN's collective preparedness for MASS but also aligns the region's legal systems with IMO-level developments, thereby reducing legal fragmentation and promoting maritime integration.

4.4.4. Comparative Value and Regulatory Takeaways

Singapore's regulatory ecosystem offers a compelling case study of how a jurisdiction with limited territorial waters but extensive maritime influence can develop a globally relevant framework for MASS regulation. Unlike countries that rely solely on either legal codification (Japan) or regulatory experimentation (Norway), Singapore has demonstrated that a hybrid, multi-scalar approach, combining national innovation with regional harmonization and global alignment, can deliver both legal predictability and technological agility.

From a comparative perspective, key strengths of Singapore's model include:

- **Sandbox flexibility with structured oversight**: By using regulatory testbeds and trial permits, the MPA enables rapid deployment of MASS while retaining

[296] ReCAAP ISC, Annual Report 2023: Emerging Threats and Regional Response Measures, https://www.recaap.org
[297] ASEAN Secretariat, ASEAN Transport Strategic Plan 2016–2025, at 47–50 (2016), https://asean.org

the legal discretion to impose operational controls, emergency response conditions, and shut-down procedures if risk thresholds are breached[298].

- **Port-centered digital transformation**: Unlike models focused solely on vessel-side autonomy, Singapore builds MASS into a broader port digitization framework, ensuring seamless integration between ship systems, terminal logistics, and maritime traffic control[299].
- **Legal interoperability through regional diplomacy**: Singapore does not isolate its MASS governance within its borders but actively disseminates its model through ASEAN, ReCAAP, and IMO collaboration, promoting a "shared legal lexicon" for autonomous shipping across developing and developed maritime States.

Nonetheless, Singapore's model is not without limitations:

1. **Absence of comprehensive legislation**: While Port Marine Circulars and testbed permits allow operational flexibility, they do not provide the same degree of legal certainty and enforcement clarity as a consolidated primary statute on MASS. As MASS transitions from experimental to commercial phases, codifying these regulatory instruments into binding law may become necessary to ensure consistency and confidence among insurers, foreign flag States, and global operators[300].
2. **Limited geographic scalability**: Given Singapore's small maritime jurisdiction, full commercial deployment of MASS will ultimately require legal interoperability with neighboring jurisdictions such as Indonesia and Malaysia—countries with more conservative legal postures on maritime innovation.
3. **Reliance on administrative discretion**: While the sandbox model is efficient, it also vests significant power in the maritime administration, potentially

[298] MPA Port Marine Circular No. 11 of 2021, Guidelines for Trials of Maritime Autonomous Surface Ships in Port Waters, https://www.mpa.gov.sg
[299] Maritime and Port Authority of Singapore, DigitalOCEANS™ Initiative, https://www.mpa.gov.sg
[300] Julian H. K. Lee, Legal Infrastructure for Autonomous Shipping: Gaps in the Singapore Context, 29 Sing. Ac. L.J. 122, 132–33 (2023)

creating regulatory unpredictability for operators lacking access to informal channels or facing inconsistent permit renewals.

Despite these constraints, Singapore’s MASS framework stands as a regional best practice, particularly in how it navigates between innovation and international law. Its model underscores the value of integrating national capability, regional diplomacy, and institutional cooperation, offering a pragmatic and exportable framework for jurisdictions seeking to balance legal certainty with technological experimentation in the maritime domain.

4.5. Conclusion to Chapter 4: Comparative and Regulatory Analysis

The comparative and regulatory examination undertaken in this chapter demonstrates that the global legal landscape governing Maritime Autonomous Surface Ships (MASS) is in a state of dynamic flux. Rather than a unified trajectory, what emerges is a **fragmented yet evolving mosaic** of national strategies, experimental regulatory frameworks, and international facilitation efforts, all attempting to reconcile the disruptive nature of maritime autonomy with existing legal norms.

Each of the jurisdictions studied—Norway, the European Union, Japan, and Singapore offers a unique regulatory architecture that reflects not only their legal traditions but also their economic priorities, technological capacities, and strategic maritime interests.

Norway exemplifies an incremental and adaptive regulatory model, relying heavily on administrative flexibility through the Norwegian Maritime Authority (NMA) and classification societies such as DNV. Its real-world testing zones, particularly those supporting the Yara Birkeland and similar projects, show that legal experimentation within controlled environments can provide valuable insights. However, this model, grounded in discretionary exemptions rather than codified law, may face limitations in scaling up or serving as a robust template for long-term commercial deployment, especially in cross-jurisdictional contexts.

The European Union represents a regulatory coordination model, where supranational institutions, especially the European Maritime Safety Agency (EMSA), attempt to harmonize Member State responses through policy guidance, soft law, and funding mechanisms like Horizon Europe. While EMSA’s reports and strategic plans offer detailed legal diagnostics, the absence of binding EU legislation on MASS creates a regulatory vacuum in some areas, allowing national fragmentation to persist.

Nevertheless, the EU’s commitment to embedding autonomy within broader sustainability and digitalization objectives signals a future-oriented governance vision, which may eventually coalesce into hard law.

Japan provides an instructive contrast as a jurisdiction that has moved toward national legislative codification. Its amendments to the Ship Safety Law and the formal creation of a national roadmap for MASS demonstrate regulatory assertiveness, reinforced by high-level policy coordination and robust public–private partnerships under the MEGURI2040 initiative. Furthermore, Japan's integrated approach to smart port development ensures that vessel autonomy is synchronized with onshore infrastructure readiness. However, while Japan's domestic legal certainty is unmatched, there remains a risk that its internal standards may diverge from international norms, thereby limiting interoperability unless closely aligned with the IMO’s eventual MASS Code.

Singapore illustrates a hybridized governance model, balancing operational experimentation with legal prudence, and playing a bridging role between domestic reform and international coordination. Its regulatory sandbox approach provides controlled flexibility, while its leadership in regional institutions such as ReCAAP and ASEAN forums allows it to project influence across Southeast Asia. Notably, Singapore’s ability to align MASS regulation with its ambitious Tuas smart port infrastructure and its role in co-hosting IMO workshops illustrates how microstate agility can translate into macro-regulatory leadership. Still, Singapore's reliance on administrative circulars and testbed permissions, without a formal legislative framework, may pose enforceability and transparency concerns as MASS enter full commercial operations.

Cross-Jurisdictional Lessons and Thematic Takeaways

Across these jurisdictions, certain common themes and regulatory trends can be discerned:

- Legal uncertainty remains pervasive, especially in defining the roles of AI systems, remote operators, and automated decision-making processes within traditional legal categories such as "master," "crew," or "operator."

- A gradual move from soft law to hard law is emerging, but most regimes continue to rely on trial frameworks, regulatory guidelines, and sandbox permits, rather than enforceable statutes or treaty amendments.
- There is a growing recognition of the need for port–vessel integration, with jurisdictions investing in smart ports and AI-based traffic management systems to complement shipboard autonomy.
- The cybersecurity dimension of autonomy, critical for the safe and secure functioning of MASS, is receiving increasing attention, but remains underdeveloped in many regulatory models.
- Most jurisdictions are taking a functional approach to equivalence, allowing autonomous systems that can demonstrate equal or superior safety to manned vessels to operate under modified conditions.

The Role of the IMO and the Road Ahead

While national and regional responses are valuable, the absence of a binding, globally harmonized legal framework remains a significant barrier to seamless international deployment of autonomous ships. The IMO's Regulatory Scoping Exercise has identified numerous areas where its instruments require clarification or amendment. The forthcoming **MASS Code**, particularly in its anticipated mandatory form, may provide the backbone for such harmonization, but progress has been gradual.

In the meantime, jurisdictions like Singapore and Japan are stepping into the regulatory void with initiatives that may set de facto standards or create competing models of governance. Whether these will complement or conflict with the IMO's eventual instruments is yet to be seen.

Bridging Toward Chapter 5

This comparative chapter underscores that while regulatory momentum exists, it remains uneven and fragmented. The legal treatment of MASS is still largely reactive, attempting to retrofit autonomous technologies into conventions designed for a crewed, analog shipping environment. What is urgently required is a proactive and cohesive legal architecture, one that reflects the realities of human, machine collaboration, supports machine-based navigation within existing liability regimes, and harmonizes national and international approaches to operational safety and compliance.

The next chapter builds on the findings of this comparative analysis to outline proposed legal reforms and policy recommendations. It will offer a structured roadmap for legislative amendments, institutional reforms, liability frameworks, and international coordination mechanisms. Special emphasis will be placed on adapting key maritime instruments, enhancing flag and port State roles, strengthening MASS certification and oversight, and encouraging the global standardization of operational and cybersecurity protocols. These recommendations aim to ensure that the integration of autonomous ships into global shipping lanes is not only technologically feasible but also legally robust, internationally harmonized, and responsive to evolving maritime risks.

CHAPTER 5

PROPOSED LEGAL REFORMS AND POLICY RECOMMENDATIONS

5.1. Introduction

The rise of Maritime Autonomous Surface Ships (MASS) marks a turning point in maritime operations, as artificial intelligence, remote navigation, and control systems increasingly displace traditional human roles onboard. This technological shift challenges the human-centric assumptions embedded in international maritime law. As outlined in earlier chapters, key legal instruments—including UNCLOS, SOLAS, COLREGs, MARPOL, and STCW—were not designed for unmanned or semi-autonomous vessels. Chapter 2 highlighted the doctrinal misfit between these treaties and MASS. Chapter 3 revealed that liability frameworks are ill-equipped to manage hybrid decision-making. Chapter 4 examined the fragmented national responses, showing that despite innovation, legal harmonization remains elusive. This chapter proposes legal and policy reforms to close the regulatory gap. Without clear, uniform standards, MASS deployment risks creating legal uncertainty, enforcement challenges, and cybersecurity vulnerabilities. Reform is not optional—it is essential to preserve the predictability and coherence of international maritime law.

The proposals are grounded in legal certainty, safety, equity, and international cooperation, and aim to:

- Amend existing conventions to reflect MASS operations;
- Define autonomy levels and legal status for remote and AI-driven systems;
- Reform liability regimes to accommodate shared human and machine control;
- Standardize certification, testing, and port access procedures;
- Establish cybersecurity norms and digital infrastructure safeguards;
- Promote a Model Law or IMO-led annex for harmonized domestic adoption.

These reforms are designed to support—not replace—national initiatives. They offer a roadmap for aligning legal structures with the evolving realities of autonomous shipping, ensuring that innovation is matched by a robust, unified, and future-ready legal framework.

5.2. Revising Core Maritime Conventions

The legal architecture that governs the global maritime domain is founded upon a set of longstanding international conventions, UNCLOS, SOLAS, COLREGs, and STCW, each designed in an era where the operation of a vessel was inherently and entirely human-centred. These instruments were not merely drafted with human command in mind; they embody fundamental assumptions about human judgment, onboard physical presence, and direct sensory perception. Maritime Autonomous Surface Ships (MASS), particularly at higher levels of autonomy, challenge these assumptions across every functional and legal dimension.

While some legal scholars and regulatory authorities have proposed flexible interpretation of these instruments to encompass autonomous technologies, such an approach is increasingly insufficient. Legal ambiguity, inconsistent national practices, and operational risks now necessitate structural reforms in the form of targeted amendments, supplementary annexes, and dedicated interpretive protocols to bring the maritime treaty regime into alignment with 21st-century realities.

This section proposes reforms to each of the four core conventions to enable safe, lawful, and accountable deployment of MASS, without compromising the baseline objectives of maritime safety, environmental protection, and international cooperation.

5.2.1. UNCLOS – Jurisdictional Oversight and Legal Definitions

The United Nations Convention on the Law of the Sea (UNCLOS) serves as the foundational legal framework for ocean governance and remains the most widely ratified maritime treaty in the world. It establishes a comprehensive regime that governs maritime zones, navigational rights, environmental protection, and crucially, the responsibilities of States over vessels flying their flags. However, while UNCLOS is technologically neutral in language, its operational and legal assumptions are decidedly anthropocentric, presuming that vessels are controlled by a human master and manned by onboard officers and crew. This presents a fundamental legal challenge in the context of Maritime Autonomous Surface Ships (MASS). As vessels increase in autonomy and transition toward partial or full machine-led navigation, the jurisdictional, definitional, and regulatory mechanisms established by UNCLOS become increasingly strained.

Human-Centric Language in Key Provisions

Article 94(2) of UNCLOS mandates that the flag State "effectively exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag." More specifically, Article 94(3) requires the flag State to maintain a registry and ensure that each ship is in the charge of "a master and officers who possess appropriate qualifications[301]."This obligation assumes the physical presence of a human operator onboard, a presumption invalidated by fully autonomous vessels that have neither a master nor crew, but operate using pre-programmed logic or machine learning algorithms. In such cases, what does "control" or "jurisdiction" mean for the flag State? Does the supervisory role exercised from a remote control center or through software updates constitute "effective jurisdiction"? Even more problematic is Article 98, which imposes a humanitarian duty on the "master of a ship" to render assistance to persons in distress at sea "insofar as he can do so without serious danger to the ship, the crew or the passengers." An unmanned vessel, by definition, lacks a human master and a crew. It may not be physically capable of rendering assistance and is certainly not capable of subjective judgment regarding danger or risk. This creates a gap in legal continuity and humanitarian expectations.

Jurisdictional Ambiguities in the Autonomous Context

The absence of legal definitions for "ship," "master," or "crew" in UNCLOS further complicates matters. Although Article 29 defines a "warship," there is no general definition of "vessel" that reflects technological neutrality or recognizes varying degrees of automation. The convention also does not account for distributed control architectures where different functions, such as navigation, maintenance, communication are handled by separate entities (e.g., software providers, remote operators, algorithm developers) across multiple jurisdictions.

This raises several unresolved legal questions:

- Who bears liability under international law when an autonomous vessel violates the rights of another State?
- How should the flag State exercise control and enforcement responsibilities over algorithmic agents that operate without human intervention?

[301]UNCLOS, supra note 6, art. 94(2)-(3)

- Can remote operators be regarded as the "master" for the purposes of flag State obligations or enforcement under Article 217 (enforcement of pollution rules)?

Without answers to these questions, the legal personality of autonomous ships under UNCLOS remains uncertain and contested.

Need for a Technologically Adaptive Framework

To accommodate MASS, UNCLOS must evolve in a manner that retains the convention's universality and normative stability while introducing the flexibility necessary to address emerging realities. This can be done not through wholesale rewriting but through the adoption of a supplementary instrument, such as a protocol or interpretive annex.

Proposed Legal Reforms:

1. **Protocol on Autonomous Maritime Navigation**: Introduce a protocol to UNCLOS that provides:
    - A functional definition of a "vessel" that includes fully and partially autonomous systems;
    - Legal recognition of remote operators or AI supervisory entities as equivalents to the "master" for purposes of Article 94(3);
    - Expanded flag State responsibilities for certifying and monitoring shore-based control centers and decision-support software as part of their jurisdictional oversight.
2. **Clarification of the Duty to Render Assistance (Article 98)**:
    - Require that MASS demonstrate technological capacity or human supervisory protocols capable of initiating distress alerts or coordinating rescue operations remotely;
    - Reframe the legal obligation so that it shifts from onboard response to functional responsibility, possibly residing in a remote control center or digital emergency services module.
3. **Guidance for Enforcement Provisions (Article 217)**:

- Develop uniform standards for audit trails, system transparency, and AI decision logging to enable effective investigation and enforcement by flag States.

These reforms must be developed in consultation with stakeholders from IMO committees, flag States, classification societies, cybersecurity experts, and MASS manufacturers. The resulting framework would not only close the definitional gaps in UNCLOS but also enhance legal certainty, thereby encouraging wider compliance and responsible innovation in the maritime sector.

5.2.2. SOLAS – Reframing Safety Standards Through Functional Equivalence

The International Convention for the Safety of Life at Sea (SOLAS**)**, originally adopted in response to the Titanic disaster in 1914 and most recently updated in 1974, is widely regarded as the cornerstone of international maritime safety law. It establishes comprehensive safety requirements regarding ship construction, life-saving equipment, fire protection, radio communications, navigation, manning, and emergency procedures. However, like UNCLOS, the SOLAS framework is predicated upon the assumption of human presence and direct human control onboard. As Maritime Autonomous Surface Ships (MASS) evolve from experimental deployments to commercial operations, this assumption no longer holds universally. MASS, particularly at autonomy Levels 3 and 4 as categorized by the IMO, may lack onboard crew, operate through software-based navigation, and rely on remote control centers or even fully automated decision-making systems. In such contexts, SOLAS's prescriptive manning, monitoring, and emergency response obligations become impractical, if not legally incompatible.

Human-Centric Design in SOLAS Provisions

Numerous SOLAS provisions are explicitly built on human roles and physical presence:

- Chapter V, Regulation 14 requires that all ships be "sufficiently and efficiently manned" to ensure safety, security, and pollution prevention[302].

[302] SOLAS, supra note 7, ch. V, reg. 14

- Regulation 34(1) states that "the master shall ensure" the safe planning and execution of the voyage, with reference to weather conditions, traffic density, and limitations of the vessel.
- Chapter III covers life-saving appliances and arrangements, including lifeboat drills, fire team coordination, and abandon-ship procedures—all based on crew participation.

Additionally, SOLAS provisions on shipboard drills, manual alarm testing, fire watch, and control of onboard ventilation systems all presuppose a physically present, human crew. MASS, especially those without crew, cannot comply with these rules without significant reinterpretation or modification. Moreover, there is no formal recognition in SOLAS of alternative forms of command, such as remote operation centers (ROCs), or of autonomous decision-making systems, regardless of whether they can demonstrate equal or greater safety outcomes.

The Need for Functional Equivalence

Rather than attempting to retrofit every regulation to MASS by analogy, a more sustainable legal approach is to adopt the principle of **"functional equivalence."** Under this principle, autonomous ships and their associated systems should be permitted to operate if they can demonstrably fulfil the underlying safety objectives of SOLAS, regardless of whether they do so through human presence or technological means. This approach would preserve the protective intent of SOLAS while enabling innovation and operational diversity in compliance strategies.

Recommended Reforms

To operationalize functional equivalence and integrate MASS into the SOLAS framework, the following legal and institutional reforms are proposed:

1. **Creation of a Dedicated SOLAS Annex for MASS**:
    - The IMO should introduce a new annex or standalone chapter within SOLAS that specifically governs autonomous vessels.
    - This annex should set goal-based standards rather than detailed prescriptive requirements, using language that refers to outcomes (e.g.,

"effective fire detection and suppression") rather than specific methods (e.g., "crew member must test fire alarm weekly").

2. **Recognition of Remote Operation Centers (ROCs) as Legal Equivalents**:
   - Remote operators and ROCs should be formally recognized in the legal framework as fulfilling the command and control functions of the "master" onboard.
   - SOLAS provisions referencing the master should include, either explicitly or through an interpretive annex, the authority of certified remote operators, subject to audit and licensing obligations by flag States.
3. **Flexible Compliance for Emergency Systems**:
   - For autonomous ships, emergency systems such as fire suppression, power shutdown, and distress signaling should be automated, remotely accessible, or algorithmically triggered.
   - Life-saving equipment regulations should be revised to permit non-human emergency protocols, such as AI-driven rerouting, remote distress communication, or virtual coordination with search and rescue authorities.
4. **Certification of Technology-Based Safety Systems**:
   - Flag States and classification societies should be empowered, through amendments to SOLAS, to certify AI-driven or remote-controlled safety systems as functionally equivalent to crew-based procedures.
   - A new category of "Autonomous Safety Certificate (ASC)" could be introduced to demonstrate SOLAS compliance through testing, validation, and system audits rather than crew drills or paper logs.
5. **Incorporation of Cyber Risk as a Safety Concern**:
   - Recognizing the increasing cybersecurity vulnerabilities associated with autonomous systems, the SOLAS annex for MASS should include mandatory provisions for:
     - Intrusion detection systems;

- Secure software update protocols;
- Redundant communications pathways;
- Cyber incident response plans.

These should be enforced through periodic cyber audits and operational simulations.

Regulatory Precedents and Global Trends

Elements of this proposed reform find support in precedent. For instance, the IMO's adoption of the **Polar Code** provides a blueprint for integrating supplementary frameworks into SOLAS. The Polar Code contains both mandatory and recommendatory elements tailored to the unique risks of Arctic and Antarctic navigation, and operates as an addendum to SOLAS and MARPOL. A similar **"Autonomous Operations Code"** could serve as a transitional regulatory document until comprehensive treaty amendments are achieved. In the private sector, classification societies such as DNV, Lloyd's Register, and ABS have already begun issuing guidelines and notations for autonomous ship safety, including standards for collision avoidance, power redundancy, and remote communication systems. These non-binding standards are increasingly used in pilot projects and may inform the drafting of an IMO-backed annex or MASS Code[303].

Conclusion: Preserving Safety Without Hindering Innovation

The integration of MASS into the global maritime fleet does not necessitate abandoning SOLAS's core mission—to safeguard life at sea. However, it does require a recalibration of its legal design and enforcement logic. The pathway forward lies in reconciling regulatory integrity with technological flexibility. By reframing SOLAS through functional equivalence and goal-based regulation, the international community can ensure that safety is not compromised by innovation but rather enhanced through rigorous, evidence-based, and adaptable compliance strategies.

5.2.3. COLREGs – Navigating Rules for the Non-Human Mariner

The Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) functions as the global "rules of the road" for maritime navigation.

[303] DNV, Recommended Practice: Assurance of Autonomous Maritime Systems, DNVGL-RP-0496 (2023); Lloyd's Register, Cyber-enabled Ships – ShipRight Procedure, (2022)

Adopted in 1972, the COLREGs are instrumental in ensuring orderly movement and collision avoidance among vessels in both open seas and congested waterways. However, these rules were crafted with a foundational premise: human observation, human judgment, and human seamanship. This renders their direct application to Maritime Autonomous Surface Ships (MASS), especially those with high levels of autonomy, both conceptually and operationally problematic. As autonomous vessels increasingly rely on artificial intelligence, sensor fusion systems, and algorithmic path planning rather than on-the-spot human reactions, the COLREGs must evolve to ensure legal clarity, safety equivalence, and international uniformity in machine-enabled navigational behavior.

Human Dependence in the Text of the COLREGs

Several key COLREG rules rely explicitly on human perception and discretionary conduct:

- **Rule 5** requires that "every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means.[304]"
- **Rule 6** on "safe speed" instructs masters to take into account visibility, traffic density, maneuverability, and human reaction time—factors which are interpreted subjectively.
- **Rule 8** mandates that action to avoid collision be "positive, made in ample time and with due regard to the observance of good seamanship."
- **Rule 2(b)** introduces flexibility, allowing mariners to depart from the rules in extraordinary circumstances if necessary to avoid danger, a clause which clearly relies on human discretion.

These rules do not contemplate scenarios where a computer makes real-time navigational decisions, or where no human operator is present onboard to evaluate or override those decisions. More fundamentally, the standard of care embedded in "ordinary practice of seamen" is undefined in the context of machine behavior, and currently lacks any recognized AI corollary.

Technological Challenges and Legal Uncertainty

[304] COLREGs, supra note 9, Rule 5

Autonomous ships navigate using a complex integration of:

- LIDAR, radar, sonar, and AIS (Automatic Identification Systems);
- Computer vision and real-time object detection;
- AI algorithms trained on historical traffic data and simulated conditions;
- Dynamic path planning logic based on environmental inputs and proximity alerts.

While these technologies often exceed human sensory capacity, they are not perfect and may struggle with ambiguous targets (e.g., small fishing boats, floating debris, erratic human behavior), or with contextual judgment (e.g., when to yield in the spirit of good seamanship). If a fully autonomous ship collides with a conventionally crewed vessel, and the machine followed a literal interpretation of the COLREGs while failing to anticipate or adapt to human unpredictability, legal fault attribution becomes uncertain. Moreover, there is currently no standardized benchmark for when an autonomous system has adequately complied with “lookout,” “safe speed,” or “evasive action” obligations. This creates inconsistency in compliance assessment, port State control inspections, insurance claims, and post-incident adjudication.

Recommended Reforms

To ensure that the COLREGs remain effective in a future where human and non-human navigators share maritime space, the following reforms are proposed:

1. Functional Recognition of Sensor-Based Lookout (Rule 5)- Rule 5 should be revised or supplemented by an annex that explicitly recognizes that automated sensory systems, such as radar-LIDAR fusion, computer vision, and sonar, may fulfill the lookout requirement if their performance meets or exceeds human detection capabilities.

Proposed Textual Addition: “For vessels operating under automated or remote control, a lookout maintained by electronic means shall be deemed sufficient if its reliability, coverage, and reaction time are certified by a competent authority.”

Flag States and classification societies should develop performance benchmarks, such as detection range in fog, minimum reaction latency, and object classification accuracy thresholds.

2. Standardizing Machine Compliance with Navigational Behavior Rules- Rules 6 and 8 rely heavily on human anticipation and contextual decision-making. Autonomous systems must be trained and tested under standardized COLREG scenarios using:

- Digital twins and traffic simulations;
- Machine-readable rule interpretations;
- AI behavioural compliance frameworks.

The IMO should establish an annex setting out **"MASS Navigational Behavior Protocols"**, outlining:

- Situational awareness thresholds;
- AI decision-making auditability;
- Rules for evasive action timing and trajectory based on vessel type and proximity.

Certification under these protocols would demonstrate rule compliance equivalency, even in the absence of a human decision-maker.

3. Clarifying the Role of Remote Operators and Human Override- For semi-autonomous vessels (Level 2 or 3), remote operators must be designated as legally responsible for compliance with COLREGs, similar to a traditional master. This role should include:

- Real-time situational monitoring;
- Authority to override automated decisions;
- Legal accountability in case of collision.

This would require amendments to COLREGs and alignment with the STCW Convention, which must recognize and train such remote operators accordingly.

4. Enabling Legal Interpretation of "Good Seamanship" for AI Systems- The ambiguous standard of "ordinary practice of seamen" should be translated into quantifiable performance indicators for autonomous systems. These could include:

- Minimum evasion angles;

- Safe distance calculations based on vessel class and speed;
- Risk assessment thresholds based on traffic density.

This would enable courts, flag States, and insurers to evaluate AI performance objectively, using system logs and decision records.

Legal Precedents and Implementation Feasibility

Some progress is already underway. In 2022, the IMO's Maritime Safety Committee acknowledged that COLREG compliance by MASS was "problematic" and recommended scenario-based rule interpretation guidance as part of the MASS Code's development[305]. Moreover, classification societies such as DNV and Lloyd's Register have incorporated COLREG-compliant behavior modules into autonomous ship design standards[306]. However, without binding amendments or interpretive instruments, reliance on national guidance risks regulatory fragmentation and undermines the predictability that COLREGs were meant to ensure.

Conclusion: Maintaining Navigational Order in a Hybrid Maritime Domain

As human and machine actors increasingly share responsibility for maritime navigation, the COLREGs must evolve from anthropocentric principles to behaviorally equivalent performance standards. This transition must be carefully managed to preserve the stability, clarity, and global uniformity of navigational rules while embracing the operational efficiencies and safety potential offered by autonomous systems. A structured, phased reform starting with interpretive annexes, followed by certification guidelines, and eventually formal amendments can ensure that autonomous ships become safe and legally visible actors within the global maritime order.

5.2.4. STCW – Evolving the Legal Concept of Maritime Competency

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, serves as the global framework for ensuring the competence and professionalism of maritime personnel. It establishes minimum qualifications for seafarers, prescribes hours of rest, mandates onboard drills, and ensures uniform certification standards. However, STCW—like other core

[305] Int'l Mar. Org., Outcome of the Regulatory Scoping Exercise for the Use of MASS, IMO Doc. MSC 103/5/2 (May 2021).
[306] DNV, Recommended Practice: Assurance of Autonomous Maritime Systems, DNVGL-RP-0496 (2023)

maritime instruments—is premised entirely on a manned vessel paradigm, where crew members are physically present onboard, executing and responding to real-time operational demands. As Maritime Autonomous Surface Ships (MASS) become more prevalent, particularly those operating at higher levels of autonomy (Levels 3 and 4 per IMO categorization), the traditional STCW framework becomes increasingly difficult to apply. MASS may operate without a master, officers, or seafarers onboard, instead relying on shore-based control centers (SCCs), AI-powered decision-making, and software-managed propulsion and navigation. This new operational model necessitates a radical rethinking of maritime competency, who qualifies as a 'seafarer,' where that person is located, and what knowledge they require to ensure safe and lawful navigation.

Challenges in Applying STCW to MASS Operations

Several provisions in STCW become difficult or irrelevant when applied to autonomous shipping:

- Regulation I/1 defines seafarers as "any person who is employed or engaged… onboard a ship.[307]"
- Chapter VIII sets minimum hours of rest and mandates the establishment of a watch keeping schedule onboard;
- Regulations II/1 to II/4 provide competency requirements for masters, mates, and navigational watch officers, assuming physical presence on the bridge;
- Emergency preparedness protocols require shipboard participation in drills, simulations, and hands-on responses to fires, evacuations, and environmental emergencies.

In the context of MASS, these provisions are either inapplicable (due to lack of onboard personnel) or fail to account for new roles that are crucial to vessel safety, namely, remote operators, AI system supervisors, and cybersecurity coordinators. These individuals may exert operational control from thousands of miles away, yet are not recognized as "seafarers" under current international law.

[307] International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, Regulation I/1, July 7, 1978, 1361 U.N.T.S. 190.

Risks of a Regulatory Vacuum

The absence of updated competency standards for remote operation and autonomous systems introduces serious legal and safety risks:

- Flag States lack guidance on how to certify or license remote operators, leading to fragmented national practices;
- Insurers and courts may struggle to determine legal responsibility in the event of a casualty involving personnel who are not officially trained or certified under STCW;
- Ports and coastal States may question the sufficiency of a ship's "manning," particularly during emergency docking, collision avoidance, or distress signaling.

This legal vacuum also undermines broader international obligations, including those under UNCLOS Article 94(4), which requires States to ensure their ships are "in the charge of a master and officers who possess appropriate qualifications.[308]"

Recommended Reforms: Expanding the Concept of Maritime Competency

To maintain the global coherence of competency standards, STCW must be reformed to reflect the changing locus of decision-making and operational control in autonomous navigation. The following legal and institutional reforms are proposed:

1. Adopt a Dedicated Annex or Code for Autonomous Vessel Personnel

The IMO should introduce a **"STCW-A" annex or code**, modeled after the existing STCW Code, that specifically addresses:

- Remote command and control roles;
- Autonomous vessel oversight and systems diagnostics;
- AI systems integration and failure management;
- Cybersecurity and data integrity protection.

[308] UNCLOS, supra note 6

This annex should set global minimum standards for the certification and training of MASS personnel, regardless of their physical location.

2. Recognize Remote Operators and Supervisors as Legal Equivalents to Onboard Officers

A new category of legally recognized maritime personnel should be created, such as:

- **Remote Master (RM)** – an individual designated with the legal authority and technical capacity to assume control of the vessel from a remote location;
- **Autonomous Systems Supervisor (ASS)** – certified personnel responsible for continuous monitoring, systems health checks, and algorithmic behavior oversight;
- **Maritime Cybersecurity Officer (MCO)** – responsible for the detection, prevention, and response to cyber threats affecting vessel control systems.

These roles must be formally acknowledged within the STCW framework as **functionally equivalent** to traditional onboard officers.

3. Create Competency-Based Training Modules for MASS Roles

Training should focus on competencies that are directly relevant to autonomous vessel operation, including:

- Interpreting and validating sensor data (LIDAR, radar, AIS);
- Navigating using AI-generated path planning;
- Emergency override procedures in case of AI failure or cyber intrusion;
- Legal obligations under COLREGs, UNCLOS, and SOLAS as applied to remote oversight.

This competency-based model should be modular and flexible, reflecting the multidisciplinary nature of remote MASS operation, combining elements of navigation, software engineering, systems control, and international law.

4. Develop a Global Registry of Certified MASS Personnel

A centralized, IMO-endorsed registry should be created to:

- Track certifications and qualifications of remote operators and system supervisors;
- Facilitate port State and flag State verification of compliance;
- Enhance transparency and cross-border recognition of qualifications.

This registry would function similarly to the White List under STCW but be digitally managed and dynamically updated.

Policy Justification and Global Alignment

There is growing support for this approach. The European Maritime Safety Agency (EMSA) has called for the development of MASS-specific certification frameworks[309]. Similarly, classification societies such as DNV and Lloyd's Register have begun issuing training guidelines for operators of remotely piloted ships. Moreover, the IMO's scoping exercise on MASS concluded that many STCW provisions would need reinterpretation or amendment for autonomous vessel integration, particularly in light of the human accountability gaps created by shore-based control[310]. In this context, updating STCW is not merely an administrative task but a legal necessity to maintain maritime safety, protect life at sea, and provide clarity for enforcement, compliance, and liability resolution.

Conclusion: Redefining the Seafarer for the Digital Age

The safe and lawful operation of autonomous vessels depends on the continued professionalism of human actors, not onboard, but behind screens, terminals, and servers. These individuals are the new seafarers of the digital maritime age. By modernizing STCW to reflect this shift, the international community can ensure that MASS are operated by qualified, certified, and accountable professionals, upholding the same high standards of safety and reliability expected of traditional crews.

5.2.5. Toward an Integrated Reform Mechanism: The MASS Protocol

As the preceding sections demonstrate, the deployment of Maritime Autonomous Surface Ships (MASS) presents unique and cross-cutting legal challenges that are not easily addressed by isolated amendments to individual maritime conventions. While

[309] European Maritime Safety Agency (EMSA), Study on the Safe Implementation of MASS in the EU (2020), https://www.emsa.europa.eu

[310] Int'l Mar. Org., *Regulatory Scoping Exercise – MASS Final Report*, MSC 103/5/3 (May 2021)

updating core instruments like UNCLOS, SOLAS, COLREGs, and STCW is essential, such amendments are politically complex, procedurally slow, and prone to national resistance. The reality is that maritime treaty reform often moves at a glacial pace, constrained by the consensus-based nature of the International Maritime Organization (IMO) and the high threshold required for formal amendments. In light of these institutional constraints, there is a compelling case for adopting a dedicated, integrated reform mechanism—a flexible yet authoritative legal framework that can evolve alongside MASS technology without undermining the integrity of existing conventions. This mechanism could take the form of a MASS Protocol: a modular, cross-referenced instrument endorsed by the IMO, designed to coordinate and clarify the application of current treaty obligations to autonomous and semi-autonomous vessels.

What is the MASS Protocol?

The MASS Protocol would be a soft-law or quasi-binding instrument—similar in design to the Polar Code, the ISM Code, or the STCW Code—that functions as a supplementary legal framework layered onto the core maritime treaties. It would not replace the existing conventions, but would:

- Interpret, contextualize, and extend their application to MASS;
- Provide uniform definitions, operational thresholds, and functional equivalencies;
- Serve as a transitional legal framework until formal treaty amendments can be achieved.

This Protocol would facilitate harmonization without requiring immediate consensus on amendments to foundational instruments, a pragmatic solution that balances legal rigor with operational urgency.

Proposed Structure of the MASS Protocol

The Protocol could be structured into several key modules:

1. **Definitions and Classification**:
    - Establishing harmonized terminology for degrees of autonomy (e.g., Levels 0 to 4), remote operators, AI decision systems, and control centers;

- Clarifying when a MASS qualifies as a “ship” for treaty application purposes, and who is considered the “master” or “operator.”

2. **Functional Equivalence Standards**:

   - Laying out technical benchmarks for compliance with SOLAS safety obligations, COLREG navigation duties, and UNCLOS flag State oversight;
   - Permitting alternative compliance routes where MASS can demonstrate equal or superior safety performance to crewed vessels.

3. **Certification and Licensing Regime**:

   - Creating templates for flag State certification of MASS systems, remote operators, and remote-control centers;
   - Incorporating third-party audits by recognized organizations (ROs) or classification societies.

4. **Competency and Training**:

   - Supplementing STCW by outlining training, qualification, and licensing requirements for new roles in MASS operation (e.g., Remote Masters, Cybersecurity Officers);
   - Requiring ongoing skills assessment and system simulation training.

5. **Cybersecurity and Data Standards**:

   - Mandating cybersecurity risk assessments, intrusion detection capabilities, and software integrity assurance;
   - Requiring MASS systems to maintain secure and retrievable logs for legal investigation and compliance monitoring.

6. **Emergency and Liability Protocols**:

   - Defining roles, responsibilities, and standard operating procedures for emergencies involving MASS (e.g., collisions, system failure, environmental hazards);

- Establishing interim frameworks for attributing liability among AI systems, remote operators, shipowners, and flag States.

7. **Compliance and Review Mechanism**:

    - Including a “review clause” that mandates periodic evaluation and updates of the Protocol in light of new technological developments and case law;
    - Encouraging data-sharing between States, industry, and academia to refine MASS best practices.

Institutional Basis and Legal Status

The Protocol could be adopted through a Resolution of the IMO Assembly or incorporated as a mandatory code under existing instruments, much like the Polar Code’s incorporation into SOLAS and MARPOL. It would not require full treaty ratification, making it a politically feasible and operationally timely solution. States could be encouraged to apply the Protocol through:

- Voluntary adoption followed by national implementation;
- Integration into Flag State audit schemes;
- Conditional port access rules and liability insurance requirements.

Additionally, the Protocol could be supported by a Model Law on MASS for national implementation, developed in cooperation with UNCITRAL or regional maritime authorities.

Comparative Inspiration: The Polar Code and ISM Code Models

Precedent exists for this type of regulatory mechanism:

- The **Polar Code** addresses the unique operational and environmental risks of vessels in polar waters. It integrates seamlessly into SOLAS and MARPOL through a combination of mandatory and recommendatory provisions.
- The **International Safety Management (ISM) Code**, adopted under SOLAS Chapter IX, sets out standards for the safe management and operation of ships, including documentation, planning, and auditing. It is enforceable through flag State control and compliance certifications.

A **MASS Protocol** could draw from both models, adopting the ISM Code's compliance architecture and the Polar Code's modular, risk-based approach.

Legal and Policy Justification

The MASS Protocol offers multiple advantages:

- **Legal clarity**: It resolves definitional ambiguities and regulatory contradictions across conventions.
- **Regulatory flexibility**: It can evolve with technology and be updated more frequently than treaties.
- **International harmonization**: It encourages consistent national practices, reducing the risk of fragmentation and legal uncertainty.
- **Operational readiness**: It allows for immediate, phased integration of autonomous vessels without requiring exhaustive renegotiation of existing legal instruments.

Such a protocol would also reinforce the IMO's central role in maritime governance, allowing it to proactively shape the legal contours of MASS regulation rather than reactively interpreting outdated provisions.

Conclusion: A Roadmap for Global Convergence

The shift to autonomy in maritime navigation represents a technological rupture with far-reaching legal consequences. Without a coordinated legal framework, States may continue to experiment in isolation, leading to fragmentation, uncertainty, and uneven safety standards. The MASS Protocol offers a unified yet adaptable solution, enabling the international community to bridge the gap between conventional maritime law and the emerging realities of artificial intelligence and remote command. By adopting such a framework, the IMO and its Member States can ensure that innovation proceeds within a predictable, transparent, and enforceable legal environment, safeguarding not only operational integrity but also the normative legitimacy of international maritime law in the autonomous age.

5.3 Developing a Liability Framework for Hybrid and Fully Autonomous Operations

The legal foundation of maritime governance rests heavily on the principle of accountability, with liability functioning as the primary mechanism for ensuring safety, enforcing legal duties, and allocating risk. In traditional maritime contexts, the attribution of liability is relatively well-defined, resting on the shoulders of shipowners, masters, crew members, and charterers, depending on the nature of the incident and applicable regime. Whether the issue involves collisions, environmental damage, salvage obligations, or cargo loss, maritime liability frameworks draw upon long-established doctrines of fault, negligence, and due diligence. However, the rise of Maritime Autonomous Surface Ships (MASS**)**, particularly those operating at higher degrees of autonomy, fundamentally disrupts this structure. As decision-making shifts from human actors to remote operators, software algorithms, and AI-driven systems, conventional models of liability struggle to identify fault, allocate responsibility, and establish a direct causal chain. The result is a growing legal vacuum that threatens to undermine not only individual accountability but also the functional effectiveness of compensation mechanisms, insurance coverage, and international regulatory oversight. This section proposes a multi-tiered liability framework that can accommodate hybrid (semi-autonomous) and fully autonomous operations, while remaining anchored in the foundational principles of maritime law: predictability, fairness, and enforceability.

5.3.1. The Problem of Attribution in the Autonomous Context

In manned vessels, liability typically stems from identifiable acts or omissions, e.g., a negligent master failing to avoid a collision, or a crew failing to secure cargo. In the case of MASS, liability becomes fragmented and obscured. Several actors may contribute indirectly or asynchronously to the outcome:

- **Shipowners**, who purchase and deploy autonomous systems;
- **Software developers**, who code the decision-making algorithms;
- **AI engineers**, who train machine learning models using real-time traffic data;
- **Remote operators**, who monitor or override MASS from shore-based control centers;

- **Manufacturers and integrators**, who provide the physical components of autonomous navigation;
- **Flag States**, which certify MASS and exercise compliance oversight.

Traditional maritime law does not clearly assign legal responsibility to these actors, especially where the incident arises from non-human judgment, software malfunction, or emergent AI behavior that lacks direct human command. Moreover, doctrines such as vicarious liability (holding shipowners liable for crew errors) or privity and knowledge (under the Limitation of Liability for Maritime Claims Convention) have not been adapted to account for distributed, non-human fault attribution.

5.3.2. Core Legal Principles at Risk

The inadequacy of existing liability doctrines in the autonomous context puts several legal principles at risk:

1. Accountability: Without clear lines of responsibility, wrongful conduct or defective systems may evade redress, undermining the deterrent function of liability law.
2. Compensability: Injured parties (e.g., victims of collision, pollution, or cargo loss) may struggle to secure damages if fault cannot be legally attributed to a party with standing or insurable interest.
3. Insurability: Underwriters may decline to provide coverage for MASS if liability attribution remains uncertain, resulting in regulatory barriers to deployment and increased operational risk.
4. Uniformity: Fragmented national responses and ad hoc interpretations of liability risk undermining the harmonization objective of international maritime law.

5.3.3. Toward a Tiered, Adaptive Liability Model

To address these challenges, an effective MASS liability framework should be tiered, technology-sensitive, and internationally harmonized. The following model is proposed:

Tier I: Retention of Shipowner Liability as Primary Layer

- **Strict liability** should attach to shipowners or operators for any damage caused by their autonomous vessels, regardless of the degree of human involvement.
- This model mirrors existing strict liability regimes under the CLC Convention for Oil Pollution Damage and the HNS Convention, which assign primary liability to the shipowner[311].

Rationale: The shipowner is best positioned to exercise system-wide oversight, ensure proper system certification, and maintain insurance. This aligns with long-standing maritime practice while accommodating non-traditional operation modes.

Tier II: Secondary Liability for Developers, Manufacturers, and Remote Operators

- **Joint and several liability** should be extended to key actors whose negligence or technical failure contributes to the harm:
    - Software developers for defective code;
    - AI trainers for inadequate data or improper modeling;
    - Remote operators for lapse in monitoring or override.
- Legal regimes should permit contribution claims or indemnity actions by shipowners against these secondary parties.

Rationale: This approach parallels product liability and tort law in other sectors (e.g., aviation and autonomous vehicles), ensuring that liability follows control, causation, and fault.

Tier III: Liability Shifting Based on Autonomy Level

- Liability attribution should differ based on the **degree of human involvement**:
    - **Level 1–2 (assisted/autonomous with crew)**: traditional fault-based liability applies to master and crew.
    - **Level 3 (remote-controlled)**: liability may shift to certified remote operators or the ROC entity.

[311] International Convention on Civil Liability for Oil Pollution Damage art. III, Nov. 29, 1969, 973 U.N.T.S. 3.

    - **Level 4 (fully autonomous)**: liability centers on the shipowner and system developers, with emphasis on design defects, certification errors, or software negligence.

- A formal **liability attribution matrix** should be adopted under the MASS Protocol or national laws to provide clarity across operational categories.

Tier IV: Mandatory Liability Insurance and Compensation Funds

- The IMO should consider establishing a **MASS Liability Fund**, akin to the IOPC Fund for oil pollution, funded by MASS operators and stakeholders.
- This would ensure victim compensation even when causation is unclear or system fault is non-attributable.
- Alternatively, a regional or EU-wide fund could be piloted for early-stage deployment.

5.3.4. Enabling Legal Tools: Logs, Audits, and Transparency

To support this liability regime, the following technical and legal tools must be integrated into the operation of MASS:

- Mandatory system logs and black-box data recorders, recording decision-making chains and environmental data;
- Certification of AI behavior logs and override triggers;
- Third-party system audits and compliance checks, conducted by recognized organizations;
- Real-time communications recording for remote operators and command centers.

These tools will not only facilitate enforcement but also assist in judicial review and insurer claims analysis.

5.2.5. Conclusion: Legal Certainty in a Distributed Environment

A robust liability regime is critical for the legitimacy and sustainability of MASS. While technology evolves rapidly, the law must anchor innovation in legal accountability, ensuring that every decision made by or through an autonomous vessel can be traced, reviewed, and remedied. The tiered model proposed here seeks to preserve the foundational values of maritime liability, certainty, fairness, compensation, and deterrence, while adapting to the distributed, machine-mediated reality of autonomous navigation. Its adoption, whether through national legislation or under a global MASS Protocol, is essential to the future integration of autonomous ships into the world's maritime legal order.

5.3. Standardizing MASS Certification, Cybersecurity, and Compliance

The successful global integration of Maritime Autonomous Surface Ships (MASS) into international waters hinges not only on legal recognition and liability reform but also on the establishment of a uniform, reliable, and enforceable certification and compliance regime**.** Certification processes provide the institutional mechanism by which the safety, reliability, and legal accountability of vessels are validated. For MASS, however, traditional certification systems are inadequate, as they were designed around shipboard systems operated by human crews, rather than algorithmically driven or remotely supervised vessels. Moreover, as MASS rely heavily on interconnected digital technologies, they are inherently vulnerable to cybersecurity threats, including system spoofing, jamming, malware intrusion, and data corruption. These vulnerabilities can compromise navigational control, collision avoidance, propulsion systems, and distress signaling, thereby turning autonomous vessels into both safety hazards and potential cyber-weapon platforms. Accordingly, this section proposes a framework for standardizing MASS certification, establishing minimum cybersecurity thresholds, and ensuring compliance through auditability and international coordination.

5.3.1. The Certification Gap in Autonomous Operations

In the conventional context, ship certification is largely handled by flag States and classification societies under SOLAS, MARPOL, and other IMO instruments. Certificates of seaworthiness, safety construction, and pollution prevention are issued based on inspections, checklists, and surveyor reports. However, these instruments:

- Do not account for autonomous decision-making systems;
- Lack criteria for evaluating AI-based navigation or autonomous machinery control;
- Do not provide guidance for certifying shore-based control centers (SCCs) or remote operators.

As a result, MASS currently fall into a regulatory gray area, with some vessels operating under experimental exemptions or ad hoc national approval schemes. This creates legal uncertainty, compliance inconsistency, and a lack of interoperability.

5.3.2. Proposed Certification Framework

A unified certification regime for MASS should be incorporated into either:

- A new annex to SOLAS or the proposed **MASS Protocol**;
- Or through IMO-endorsed guidelines harmonized across flag States and classification societies.

The certification framework should include:

1. **Vessel Autonomy Rating System (VARS)**
    - Adopted globally, VARS would classify vessels based on degree of autonomy (Levels 0–4);
    - Each level would correspond to different certification requirements (e.g., fail-safe protocols, human override mechanisms, system redundancy).
2. **System Performance Certification (SPC)**
    - AI modules and decision-support systems must pass standardized testing scenarios;
    - Certification to cover:
        - Collision avoidance and COLREG compliance;
        - Emergency handling;
        - Environmental monitoring systems;
        - Human-machine interface reliability.
3. **Remote Control Center Certification (RCCC)**
    - SCCs must be certified for:
        - Secure communication architecture;
        - Operator training and licensing;
        - Redundancy and blackout procedures;

  - Situational awareness dashboard calibration.

4. **Behavior Logging and Black Box Integration**
   - All MASS must include tamper-proof logging systems capturing decisions, sensor inputs, overrides, and system alerts;
   - These logs must be retained for a minimum time and made accessible to flag States, insurers, and investigation bodies.

5.3.3 Cybersecurity as a Regulatory Imperative

The cybersecurity dimension is no longer a technical afterthought—it is a core component of safety, environmental protection, and compliance enforcement. The vulnerability of autonomous ships to cyberattack has been highlighted in several industry reports and trial exercises, including by the IMO's Maritime Safety Committee and the International Union of Marine Insurance (IUMI)[312].

Common cyber threats include:

- GPS spoofing and positioning data manipulation;
- Command injection attacks that seize propulsion or steering systems;
- Remote malware installation to shut down safety protocols or communication links.

Recommended Cybersecurity Measures:

1. **Mandatory Cyber Risk Assessment (CRA)**
   - Each MASS operator must complete a CRA prior to flagging or insurance issuance;
   - Assessment must cover system architecture, software integrity, communication protocols, and emergency fallback capacity.

2. **Cybersecurity Standards Compliance Certificate (CSCC)**
   - A certificate akin to ISM Code Safety Management Certificates;

[312] International Union of Marine Insurance (IUMI), *Cyber Risk in Autonomous Shipping* (2022), https://iumi.com

- Issued by classification societies after independent penetration testing and system audit.

3. **Secure Software Development and Update Protocols**

    - Remote updates must be authenticated and logged;
    - Real-time anomaly detection systems should flag suspicious behavior and auto-isolate critical systems.

4. **Maritime Cybersecurity Code of Practice**

    - The IMO should issue a code (building on its 2017 Guidelines on Maritime Cyber Risk Management[313]) tailored for MASS, with compliance incentives tied to port access or liability protection.

5.3.4. Compliance Monitoring and Enforcement

Even with a certification and cybersecurity framework in place, enforcement is vital. The system must include:

- Periodic audits of MASS and SCCs, especially when significant software updates are installed;
- Unannounced inspections by port State control (PSC), focused on digital logs, AI logic transparency, and operational performance;
- Incident reporting obligations, where MASS must transmit fault codes and incident data to flag States and classification societies after any deviation from expected behavior;
- Loss-of-control alerts that inform coastal States in real-time when a MASS enters a critical failure or emergency override mode.

Additionally, compliance with the certification regime should be integrated into:

- Liability insurance frameworks, where insurers require proof of MASS certification;

[313] International Maritime Organization, Guidelines on Maritime Cyber Risk Management, IMO Doc. MSC-FAL.1/Circ.3/Rev.3 (Apr. 4, 2025), available at https://wwwcdn.imo.org/localresources/en/OurWork/Facilitation/FAL%20related%20nonmandatory%20documents/MSC-FAL.1-Circ.3-Rev.3.pdf.

- Flag State performance audits, under the IMO's Voluntary Member State Audit Scheme (VIMSAS);
- Port access restrictions, where non-compliant MASS may be denied entry under port State control norms.

5.3.5. Conclusion: Embedding Trust in Autonomy

Certification and cybersecurity compliance are not bureaucratic hurdles, they are preconditions for legitimacy, safety, and commercial viability in the autonomous era. A vessel that cannot demonstrate AI transparency, cyber-resilience, and human fallback capability should not be permitted to operate in international waters. The international community must therefore establish uniform certification benchmarks, recognise remote operational structures, and embed digital accountability mechanisms within maritime governance. By doing so, MASS can be integrated into the legal ecosystem of global shipping in a manner that promotes operational trust, legal predictability, and institutional enforcement

5.4. Port-State and Flag-State Responsibilities in the Autonomous Era

The effective regulation of Maritime Autonomous Surface Ships (MASS) requires not only innovation in vessel design and liability frameworks, but also a redefinition of the traditional roles played by flag States and port States. These two regulatory pillars of the maritime legal system serve as the primary custodians of safety, compliance, and enforcement. Flag States are responsible for ensuring that ships flying their flag comply with international law, while port States exercise control over foreign vessels that enter their jurisdiction, providing a secondary check on compliance. In the era of autonomous navigation, however, these responsibilities are being redefined and challenged. Traditional enforcement tools such as onboard inspections, logbook reviews, and interviews with the master or crew become impractical when there is no physical crew or when the ship's critical systems are controlled remotely or through artificial intelligence. This section explores how flag and port State responsibilities must evolve to remain effective, fair, and technologically relevant in the face of MASS operations.

5.4.1. Flag State Responsibilities: From Seafarers to Systems

Under UNCLOS Article 94, flag States must maintain effective jurisdiction over ships flying their flag. For MASS, this entails adapting oversight mechanisms to include:

- Remote Operation Centers (ROCs): Certification and auditing of ROCs and personnel as part of the flag State's maritime administration.
- Digital Documentation: Implementation of real-time, digitally verifiable certificates replacing traditional paper logs and declarations.
- AI Registry Systems: Creation of certified databases for autonomous software, with revalidation protocols following updates or incidents.
- Expanded Liability Frameworks: Legal clarity on responsibilities of shipowners, AI developers, and operators, backed by enforcement mechanisms under national legislation.

5.4.2. Port State Control: Adapting to Crewless Inspections

Port State Control (PSC) must evolve as MASS lack crew, onboard documentation, or physically inspectable systems. Key reforms include:

- Digital Portals for Remote Audits: Submission of AI logs, compliance records, and system diagnostics before port entry.
- Conditional Port Access: Certification in cybersecurity and operator licensing as a prerequisite for docking.
- Specialized PSC Teams: Inclusion of AI and digital forensic experts in inspection units.
- Post-Incident Authority: Legal rights to retrieve logs and audit software post-incident in coordination with flag States.

5.4.3. Resolving Jurisdictional Overlaps

The fragmented operational structure of MASS complicates accountability. To ensure coherent oversight, States should:

- Establish bilateral enforcement protocols for ROC and software audits.
- Adopt global attribution principles to determine jurisdiction based on control and proximity to incidents.
- Enter Mutual Recognition Agreements (MRAs) for reciprocal validation of ROC and AI system certifications.

5.4.4. Coordinated Oversight Framework

The IMO should embed a Flag and Port State Oversight Framework within the MASS Code, comprising:

- Unified audit and inspection templates,
- Risk-based screening protocols,
- Baseline standards for AI transparency and cyber hygiene.

Integration into the IMO Member State Audit Scheme (IMSAS) would ensure global consistency and raise compliance standards.

5.4.5. Conclusion: Ensuring Control Without Physical Presence

Autonomy does not negate the need for legal oversight, it merely changes its location, tools, and targets. In the MASS context, flag and port States must transition from inspecting people and paper to auditing systems, data flows, and distributed accountability chains. By adopting digital certification, remote compliance validation, and jurisdiction-sharing mechanisms, States can retain control over maritime safety and legal enforcement, even when no one is physically onboard. The future of State responsibility in shipping will be defined not by visibility on the bridge but by verifiability of control, whether through code, oversight, or algorithmic audit trails.

5.5. Proposals for International Harmonization and Model Law Development

The current regulatory environment for Maritime Autonomous Surface Ships (MASS) is fragmented and inconsistent, with divergent national approaches creating legal uncertainty in areas such as liability, certification, and enforcement. To mitigate this, two complementary solutions are proposed:

1. The adoption of a binding international instrument under the IMO; and
2. The creation of a Model Law to guide national legislation and promote coherence across jurisdictions.

5.5.1. The Case for International Harmonization

Legal ambiguity in the MASS domain impacts insurance, port access, flag State control, and cybersecurity. Without harmonization:

- Operators face inconsistent compliance burdens;

- Insurers struggle to assess risk accurately;
- Cross-border MASS navigation remains legally unstable.

5.5.2. Toward a Unified Instrument: The MASS Code

The IMO's preliminary steps toward a MASS Code should be accelerated and expanded. The Code should:

- Define autonomy levels and AI-based operations;
- Establish tiered compliance regimes;
- Mandate standards for certification, cyber resilience, and emergency protocols;
- Enable mutual recognition of digital credentials.

The Code could be formalized as an annex to SOLAS or adopted through a new convention, following precedents like the Polar Code.

5.5.3. A Model Law on Autonomous Maritime Operations

A Model Law can help States align domestic regulations with international standards, accommodating local legal systems and capacities. Spearheaded by IMO, UNCITRAL, or regional bodies, the Model Law would:

- Provide definitions for MASS, SCCs, and degrees of autonomy;
- Address registration, licensing, and liability allocation;
- Include rules on cyber compliance, inspections, and dispute resolution.

5.5.4. Regional Pilot Frameworks and Phased Implementation

Pending global agreement, a regional approach can serve as a bridge:

- EU, ASEAN, and IMO corridors may pilot recognition of autonomous ship certifications;
- PSC frameworks (e.g., Paris MOU) can provide templates;
- Financial institutions can fund capacity-building for developing States.

5.5.5. Conclusion: Legal Coherence for Global Navigation

Without harmonization, MASS may be governed by a patchwork of local laws, undermining predictability in global trade. A dual-track strategy—global code plus domestic model law—offers the best path forward, enabling safe, scalable, and legally coherent autonomous shipping while respecting State sovereignty.

5.6. Conclusion to Chapter 5: Proposed Legal Reforms and Policy Recommendations

This chapter has set forth a comprehensive legal and policy blueprint for enabling the safe, accountable, and coherent integration of Maritime Autonomous Surface Ships (MASS) into the global maritime legal framework. Recognizing the unprecedented transformation brought about by ship autonomy from AI-led decision-making and remote command centers to the elimination of traditional onboard crews, Chapter 5 has addressed the urgent need to modernize and harmonize maritime law across multiple legal regimes. The discussion began with a detailed critique of the core international conventions, UNCLOS, SOLAS, COLREGs, and STCW, highlighting the structural and definitional mismatches that render many of their provisions ill-suited to regulating autonomous operations. These instruments, while robust in the manned-ship paradigm, assume human presence, continuous crew-based oversight, and analog compliance mechanisms. The proposed reforms, therefore, call for the adoption of a functional equivalence approach, allowing non-human systems and remote operators to fulfil legal roles traditionally reserved for masters and crew, provided they meet or exceed equivalent safety and performance standards. From there, the chapter advanced a tiered liability framework designed to address the diffuse and hybrid nature of fault in autonomous operations. This model ensures continuity with existing strict liability regimes for ship owners while introducing accountability for software developers, AI engineers, remote operators, and other actors responsible for decision-making or system failure. The framework also recommends the establishment of compensation funds and liability attribution matrices to fill gaps where fault is ambiguous or causally distributed across multiple jurisdictions. Recognizing the central role of system integrity and trust in enabling autonomous navigation, Section 5.3 proposed a standardized MASS certification regime, encompassing not only the vessel and its onboard systems, but also the remote-control centers, operators, and cyber-physical infrastructure involved in operation. A parallel emphasis was placed on cybersecurity readiness, where regulatory obligations must evolve to include secure communications, data logging, system redundancy, and AI audit trails. The chapter further examined the evolving responsibilities of flag States and port States, whose enforcement and oversight models must now shift from physical presence and crew interviews to the supervision of digital logs, remote command functions, and distributed system architectures. To remain effective, States must adopt new mechanisms of digital certification, remote auditability, and real-time system access, supplemented by coordinated jurisdictional arrangements.

Finally, the chapter proposed a two-pronged approach to global legal harmonization:

1. The development of a MASS Code, either as a standalone IMO convention or as a binding annex to existing conventions, which would consolidate technical standards, performance baselines, and regulatory expectations in a unified legal instrument;
2. The introduction of a Model Law on Autonomous Maritime Operations, to guide national implementation and ensure consistency across jurisdictions with varying legal traditions and levels of technological adoption.

Together, these reform pathways aim to construct a legally coherent, technologically adaptive, and internationally recognized framework for the governance of autonomous shipping. In the absence of coherent legal integration, MASS will remain experimental and exclusionary, confined to special zones and subject to divergent State practices. If, however, the reforms outlined in this chapter are adopted through multilateral collaboration, regulatory foresight, and capacity-building, autonomous ships can become a transformative force for safer, greener, and more efficient global maritime transport within a legal system that is not only prepared for the future but capable of shaping it.

CHAPTER 6

CONCLUSION AND FINAL REFLECTONS

6.1. Introduction

The 21st-century maritime domain is being radically reshaped by the advent of Maritime Autonomous Surface Ships (MASS), marking a paradigm shift not only in ship design and operation but in the very legal architecture that has governed the seas for centuries. The core questions this dissertation set out to examine whether the current international legal framework is adequate to regulate the emerging realities of autonomous navigation, has been answered through a multi-layered analysis of existing conventions, national practices, liability doctrines, and prospective regulatory models. The overwhelming conclusion is that the law, as it stands, is neither conceptually nor practically prepared to accommodate the operational, ethical, and jurisdictional complexities introduced by autonomous ships. This final chapter revisits the core findings, synthesizes the theoretical and doctrinal contributions of the research, outlines forward-looking implications, and identifies areas for continued legal evolution. It closes by offering normative reflections on how legal systems should approach technological disruption, particularly when that disruption challenges not only administrative systems but the very assumptions underlying maritime governance.

6.2. Synthesis of Research Findings

6.2.1. The Inadequacy of Existing Maritime Conventions

The analysis in Chapters 2 and 3 made it abundantly clear that foundational instruments like UNCLOS, SOLAS, COLREGs, and STCW are predicated on a maritime order centered around the human mariner. They reflect a world in which a ship is crewed, commanded by a master onboard, and operated using real-time human observation, discretion, and intervention. MASS challenges each of these assumptions. The lack of human presence onboard not only strains compliance with procedural mandates such as onboard drills, lookout requirements, or emergency musters, but also undermines liability models that rely on fault attribution to identifiable individuals. For example, the obligation under UNCLOS Article 94(3) for States to ensure that ships are "in the charge of a master and officers who possess appropriate qualifications" cannot easily be fulfilled where the vessel is operated by software and supervised remotely. Similarly, the collision rules in COLREGs, based on the visual and auditory judgment of the "ordinary seaman", are conceptually incompatible with AI-driven navigation systems. The absence of legally recognized equivalents for roles such as "master," "crew," or "lookout" in these instruments' leaves MASS in a legal limbo that cannot be resolved through mere interpretive flexibility.

6.2.2. The Fragmented National Landscape

Chapter 4 underscored the regulatory divergence emerging at the national and regional levels. While countries like Norway, Japan, and Singapore have taken early steps toward integrating MASS into domestic legal systems through sandbox environments and legislative amendments, their approaches differ substantially. The EU's model, driven by coordination through EMSA and Horizon Europe initiatives, further adds to this diversity. What this case studies reveal is a clear lack of harmonization. Definitions vary, certification models are inconsistent, liability regimes are nascent or missing, and port access standards are unclear. This disunity undermines the central principles of maritime law, uniformity, predictability, and global interoperability.

6.2.3. Legal Black Holes in Liability and Compliance

Chapter 3 illustrated the collapse of traditional liability structures in the face of autonomous decision-making. When a MASS causes harm through a collision, environmental damage, or navigational error, existing doctrines struggle to identify the responsible party. Fault-based models assume human error; strict liability models assume physical control. But what if the decision was made by a machine learning algorithm reacting in real time to dynamic inputs? Or what if no human operator had situational awareness at the time of the incident? Similarly, compliance regimes based on physical inspection, onboard documentation, and crew interviews cannot function where no such systems or personnel exist. Flag and port States are forced to regulate remotely, often without the tools, standards, or jurisdictional agreements necessary to do so effectively.

6.3. Legal and Institutional Reforms: Summary of Proposals

Chapter 5 offered a detailed, structured roadmap for regulatory reform. The key proposals included:

1. Rewriting or supplementing core conventions with annexes or protocols that define functional equivalents to human roles and incorporate goal-based safety standards.

2. Creating a tiered liability model that allocates responsibility based on control, system architecture, and causation, extending accountability to software developers, system integrators, and remote operators.
3. Establishing a unified MASS certification regime that includes AI performance testing, cybersecurity validation, remote operator licensing, and behaviour logging protocols.
4. Redefining port and flag State functions to accommodate remote auditing, digital compliance verification, and cooperative jurisdictional enforcement.
5. Launching international harmonization efforts through an IMO-led MASS Code and a parallel Model Law on Autonomous Maritime Operations for national adoption.

These proposals are designed not as isolated fixes, but as mutually reinforcing reforms that together can support a holistic, globally integrated legal ecosystem for MASS.

6.4. Normative Reflections on Law and Technological Change

MASS are not simply technical innovations; they are legally transformative phenomena. They compel us to ask: What is a ship? Who is responsible when machines act? How do we ensure safety, justice, and accountability when decisions are made by distributed systems rather than individuals? These questions transcend the domain of maritime law. They belong to a broader conversation about law in the algorithmic age. If the law is to remain relevant, it must evolve to recognize machine agency, while insisting that human accountability remain central. Legal personhood need not be extended to machines, but the responsibility for machine behavior must be clearly mapped and regulated through human institutions. Moreover, the experience with MASS reveals a deeper insight: that regulation must precede crisis. Unlike prior maritime innovations that were integrated into law ex post, autonomous shipping requires legal foresight. The stakes, commercial, environmental, and ethical, are too high for reactive governance.

6.5. Policy Implications and Global Governance Priorities

Several high-level policy imperatives emerge from this research:

- **Global convergence must be prioritized**. The IMO should fast-track the MASS Code and establish interim agreements on certification and port access standards.
- **Capacity-building for developing States** is essential. As automation advances, legal knowledge and institutional readiness must be equitably distributed.
- **Digital transparency should be a legal mandate**. AI decision logs, override records, and control system diagnostics must be made legally accessible for investigation and adjudication.
- **Stakeholder inclusion** must be broadened. Shipowners, seafarers' unions, insurers, technologists, and environmental bodies all have stakes in the autonomous future of shipping.

6.6. Future Research Avenues

The rapid development of MASS technology calls for continued academic and institutional inquiry. Key areas of future research include:

- Ethical frameworks for machine navigation, particularly where human life is at risk;
- Legal frameworks for AI auditing and explainability;
- Integration of blockchain or distributed ledger technologies for MASS compliance and traceability;
- Sociological impacts of automation on the seafaring workforce and maritime labor law;
- Comparative analysis of AI governance across transportation sectors, with lessons from aviation and autonomous vehicles.

6.7. Closing Reflections

This dissertation has argued that the law must not merely react to innovation, but help shape it. The oceans of the future will not be governed solely by traditional seamanship, but by software, sensors, and satellite-linked control systems. These tools offer immense promise, safer navigation, reduced emissions, lower costs, but also pose new risks. The challenge for law is not to resist this transformation, but to ensure it is ethical, equitable, and enforceable. By embracing regulatory adaptability, preserving international uniformity, and embedding legal accountability into digital systems, the maritime community can ensure that autonomous ships are not merely technologically successful, but legally and socially legitimate. In doing so, it will affirm the enduring principle that the rule of law, not the rule of code, remains the anchor of international maritime order.

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