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ISSN: 2582-6433

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CHARTING UNCHARTED WATERS: TOWARDS A COHERENT LEGAL REGIME FOR MARITIME AUTONOMOUS SURFACE SHIPS UNDER INDIAN AND INTERNATIONAL LAW.

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Abstract

The rapid emergence of Maritime Autonomous Surface Ships ("MASS")—spanning remotely controlled vessels to fully autonomous ships—promises transformative gains in efficiency, safety, and sustainability, yet exposes profound gaps in legal frameworks premised on human mastery of ships. This Article proceeds in four parts. Part I critically examines the International Maritime Organisation's (IMO) 2018–2024 regulatory scoping exercise, which defined four degrees of autonomy and charted a roadmap for a non-mandatory, goal-based MASS Code by 2025, followed by an experience-building phase (2026–2028) and a mandatory Code by 2032. Part II analyses India's Admiralty (Jurisdiction and Settlement of Maritime Claims) Act 2017, Coastal Shipping Bill 2024, and Carriage of Goods by Sea Bill 2024, identifying lacunae in jurisdictional reach, liability allocation, cyber-risk integration, and environmental governance. Part III surveys comparative liability regimes—France's maritime product-liability jurisprudence, the EU Product Liability Directive and AI Act high-risk obligations, and U.S. admiralty negligence doctrines—to propose a two-tier model reconciling strict liability for core autonomy failures with fault-based apportionment where human oversight exists. Part IV offers targeted reforms: enacting a dedicated MASS Regulation Bill; amending definitions to recognise "constructive presence" of remote-control centres; embedding mandatory cyber-security and real-time GHG telemetry chapters in domestic rules; adopting presumptive strict liability, rebuttable only by gross negligence; mandating lifecycle emissions baselines for green-corridor licences; and fast-tracking STCW-Plus endorsements for remote-operator competency. By weaving treaty interpretation, statutory critique, and comparative analysis, this Article charts a principled hybrid pathway toward coherent, innovation-friendly maritime

ISSN: 2582-6433

governance.[1]

II. Introduction

Maritime transport has entered an era of unprecedented technological transformation. The development of Maritime Autonomous Surface Ships ("MASS")—ranging from vessels equipped with decision-support algorithms to fully autonomous, crewless ships—heralds efficiency gains, enhanced safety, and reduced environmental impact. Pioneering projects such as the European MUNIN initiative demonstrated in-sea unmanned navigation of bulk carriers through advanced sensor integration and shore-based oversight,[2] while Norway's Yara Birkeland achieved remote operation of an electric feeder vessel, projecting the elimination of over 40,000 annual diesel-truck journeys.[3] Rolls-Royce's AAWA and Finferries' Falco trials further validated autonomous ferry operations, recording more than 400 hours of collision-avoidance and automatic-berthing manoeuvres without onboard crew.[4]

Yet, this maritime revolution collides with a legal architecture crafted for human-crewed ships. The United Nations Convention on the Law of the Sea ("UNCLOS") entrusts flag states with vessel safety and due diligence obligations, presuming masters and watchkeepers physically aboard (Arts. 94, 98).[5] The International Convention for the Safety of Life at Sea ("SOLAS") mandates minimum safe manning (Ch. V), and the International Regulations for Preventing Collisions at Sea ("COLREGs") require a "proper look-out" by sight and hearing (Rule 5) and fault-based navigation rules (Rule 2).[6] The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers ("STCW") sets training standards assuming onboard competence,[7] and India's Merchant Shipping Act 1958 prescribes crew-based certification and liability regimes.[8]

These texts, conceived in the age of analogue seamanship, lack mechanisms to address unmanned vessels' unique challenges. Three core issues emerge:

[1] IMO, Regulatory Scoping Exercise on MASS, MSC 99–108 Reports (2018–2024); EU AI Act, Regulation 2024/1689; Admiralty Act 2017, §§3–5; Coastal Shipping Bill 2024; Carriage of Goods by Sea Bill 2024; UNCLOS Arts. 94–98.
[2] Cordis, MUNIN Final Report (2015).
[3] Yara Birkeland | The first zero emission, autonomous ship, Yara.com (2020).
[4] Rolls-Royce & Finferries, World's First Fully Autonomous Ferry Demonstration (2018).
[5] United Nations Convention on the Law of the Sea Arts. 94, 98 (1982).
[6] COLREGs Rules 2, 5 (1972).
[7] STCW Convention Chapters III–V (1978).
[8] Merchant Shipping Act 1958, §§ 104–106.

ISSN: 2582-6433

First, **jurisdictional competence**. Autonomous vessels may be controlled from shore-based centres located outside the vessel's physical territorial waters, raising questions about arrest jurisdiction, enforcement of in rem claims, and regulatory oversight when the vessel's "mind" is ashore yet its hull operates in diverse maritime zones.[9] Absent statutory "constructive presence" provisions, enforcement authorities risk impotence against owners and operators who exploit physical-control disconnects.

Second, **liability allocation**. Classical negligence-based collision law—rooted in human error doctrines—struggles to assign fault when decisions are generated by algorithms.[10] Victims of collisions or wrongful acts by MASS may face evidentiary hurdles proving defect or negligence, necessitating a shift toward presumptive strict liability for system failures to ensure compensation and incentivise safe design.[11]

Third, **risk governance**. Autonomous vessels introduce novel cybersecurity and environmental considerations. International Maritime Organisation ("IMO") Resolution MSC.428(98) mandates cyber-risk integration into the ISM Code by 2021, yet these guidelines lack binding force and statutory anchorage in many jurisdictions.[12] Environmental due diligence obligations under UNCLOS Art. 194 require states to prevent transboundary harm, but existing MARPOL Annexe VI and domestic pollution rules do not account for lifecycle greenhouse-gas telemetry or automated emissions controls inherent to MASS.[13]

This Article addresses these gaps through a comparative, doctrinal inquiry. Part III examines the IMO's 2018–2024 scoping exercise, which defined four degrees of autonomy and charted a roadmap for a non-mandatory, goal-based MASS Code by mid-2025, followed by an experience-building phase (2026–2028) and subsequent mandatory Code by 2032. Part IV analyses India's Admiralty (Jurisdiction and Settlement of Maritime Claims) Act 2017, Coastal Shipping Bill 2024, and Carriage of Goods by Sea Bill 2024, identifying lacunae in jurisdictional reach, liability regimes, cyber-risk integration, and environmental governance. Part V surveys comparative liability frameworks—under the EU Product Liability Directive, the EU AI Act's high-risk AI obligations, and U.S. admiralty negligence doctrines—to propose

[9] Admiralty (Jurisdiction and Settlement of Maritime Claims) Act 2017, § 3.
[10] Choi & Qi, Regulating Cyber Security of MASS, 16 J. E. Asia & Int'l L. 2 (2023).
[11] European Parliament, EU AI Act, Regulation 2024/1689 (2024).
[12] IMO Res. MSC.428(98) (2021).
[13] IMO GHG Strategy (2023); Merchant Shipping (Prevention of Pollution) Rules 2009.

ISSN: 2582-6433

a two-tier model marrying strict liability for core autonomy failures with fault-based apportionment where human-in-the-loop oversight obtains. Part VI offers targeted policy recommendations: enacting a dedicated MASS Regulation Bill; amending definitional and jurisdictional provisions to recognise "constructive presence" of remote-control centres; embedding binding cyber-security and real-time GHG telemetry chapters in domestic rules; adopting presumptive strict liability, rebuttable only by gross negligence; mandating lifecycle emissions baselines for green-corridor licenses; and fast-tracking STCW-Plus endorsements for remote-operator competency.

By weaving treaty interpretation, statutory critique, and comparative legal analysis, this Article charts a principled hybrid pathway to transform fragmented regulation into a coherent tapestry—one that safeguards public interests, fosters technological innovation, and positions India at the forefront of autonomous maritime governance.

III. Literature Review

Scholarly engagement with Maritime Autonomous Surface Ships (MASS) has burgeoned across technical, legal, and socio-legal domains. Early technical analyses, such as the MUNIN project, demonstrated the real-world feasibility of shore-supervised autonomy and highlighted regulatory ambiguities under core navigational rules.[14] TransNav's operational study distilled five essential tasks—data acquisition/fusion, collision and grounding avoidance, voyage plan navigation, human–machine interface, and minimum-risk fallback—underscoring the need to define performance standards and redundancy requirements for sensor and cyber-security systems.[15]

Parallel legal scholarship has examined the adequacy of existing IMO instruments. Abramowicz-Gerigk and Burciu's Gdynia Maritime University study traced the IMO's scoping exercise through MSC 105 and MSC 108, stressing that situational-awareness frameworks for Remote Operations Centre (ROC) operators must address perception, comprehension, and anticipation under remote-sensing constraints.[16] Frontiers in Marine Navigation and Safety of Sea Transportation contrasted the 2018–2024 MSC sessions, observing that MSC 108's revised

[14] MSC 99/5/6, Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships, IMO (Mar. 12 2018).
[15] T. Abramowicz-Gerigk & Z. Burciu, Situational Awareness in Autonomous Shipping, TransNav 18 (4) (Dec. 2024).
[16] Semantic Scholar, Operations of Maritime Autonomous Surface Ships, TransNav 12 (2) (2018).

ISSN: 2582-6433

roadmap integrates amendments to SOLAS and anticipates a mandatory MASS Code by 2032, but cautioned that human-automation responsibility gaps remain unresolved.[17] Semantic Scholar's 2020 Applied Sciences review synthesised these findings and proposed hazard-analysis methods—System-Theoretic Process Analysis (STPA) and Functional Resonance Analysis Method (FRAM)—to bolster safety case development for autonomous vessels.[18]

Comparative regulatory literature situates the IMO process within broader AI governance trends. The EU's AI Act (Regulation 2024/1689) classifies autonomous navigation systems as "high-risk" AI, mandating rigorous risk assessments, data-quality controls, transparency obligations, human-oversight mechanisms, and incident-logging procedures—requirements envisaged to underpin MASS performance standards.[19] U.S. legal scholarship has advocated extending the Restatement (Third) of Torts: Products Liability framework to software components in maritime contexts, arguing that an AI-specific design-defect regime would align with admiralty principles while ensuring victim compensation.[20]

Despite this multidisciplinary momentum, scholars converge on persistent gaps: first, **jurisdictional uncertainty** regarding in rem enforcement against shore-based control centres; second, **liability allocation** when algorithmic decisions replace human judgment; and third, **risk governance** deficits in cybersecurity and life-cycle environmental monitoring. This Article builds on these foundations by integrating doctrinal exegesis of Indian statutes, comparative liability paradigms, and policy design insights to craft a coherent legal regime for MASS.

IV. Doctrinal Analysis

A. Jurisdiction and Arrest under India's Admiralty Act Section 3 of the Admiralty (Jurisdiction and Settlement of Maritime Claims) Act 2017 vests High Courts with in rem jurisdiction over "any ship" that "is within the territorial waters" of the court at the time of filing, whether it be in port or transit."[21] Based on UNCLOS's 12-nautical-mile baseline definition,[22] this confines arrest jurisdiction to vessels physically inside a High

[17] T. Abramowicz-Gerigk & Z. Burciu, supra note [15].
[18] Appl. Sci. 10 (2020), "Autonomous Vessels: Hazard Analysis via STPA and FRAM."
[19] Regulation 2024/1689, EU AI Act (2024).
[20] Restatement (Third) of Torts: Products Liability § 2 (1998).
[21] Admiralty (Jurisdiction and Settlement of Maritime Claims) Act 2017, § 3.
[22] United Nations Convention on the Law of the Sea arts. 3(1), 5 (1982).

ISSN: 2582-6433

Court's maritime limits. In *Owners of M.V. Korea Chemi v. Siluvaipichai*, the Kerala High Court held it lacked jurisdiction to arrest the M.V. Korea Chemi after its collision 48 nm off Kerala because at the time of the admiralty suit, the unmanned tanker was berthed at Nhava Sheva (Mumbai), outside Kerala waters.[23] The plaintiffs' invocation of in rem relief thus failed despite the collision occurring within Kerala's territorial sea. Similarly, in the *M.V. MSC Elsa III* sister-ship arrest, the Kerala High Court initially ordered detention of the MSC Polo 2—an Elsa III sister vessel—at Vizhinjam Port to secure ₹85,000 compensation, only to vacate the order on jurisdictional grounds when MSC Polo 2 lay beyond 12 nm.[24]

These decisions expose a critical lacuna: shore-based Remote Operations Centres (ROCs) controlling unmanned vessels fall outside territorial arrest reach. To prevent enforcement evasion, India must legislate a "constructive presence" fiction deeming ROCs or flag-state-certified remote-control hubs co-extensive with their vessels for jurisdictional purposes.

B. Liability Allocation: From Fault to Presumptive Strict Liability COLREGs Rule 2 and the Merchant Shipping Act 1958 § 345 preserve a negligence-based collision regime, premised on human master/crew error.[25] Yet autonomous navigation algorithms—ranging from sensor fusion modules to path-planning AI—embody complex software that victims cannot feasibly test for defects or negligence. The EU Product Liability Directive 85/374/EEC imposes strict liability for defective products (including software § 2(1)), and the EU AI Act (Regulation 2024/1689) classifies autonomous navigation AI as "high-risk," mandating conformity assessments, quality management, and transparency.[26] U.S. admiralty and tort scholars advocate extending the Restatement (Third) of Torts: Products Liability's strict-liability paradigm to software defects, treating defects in core autonomy modules as design defects subject to § 2(b) liability without fault.[27]

A two-tier model best reconciles public protection with innovation:

[23] Owners of M.V. Korea Chemi v. Siluvaipichai, Kerala H.C. (2025) (as reported in CourtPractice).
[24] "Kerala High Court Orders Arrest of an MSC Boxship Over Elsa 3 Sinking," The Maritime Executive (June 19 2025).
[25] COLREGs Rules 2, 5 (1972); Merchant Shipping Act 1958, § 345.
[26] Council Directive 85/374/EEC on liability for defective products; Regulation 2024/1689, EU AI Act, art. 6–7.
[27] Restatement (Third) of Torts: Products Liability §§ 1–2; "Third Circuit Turns to Restatement 3rd of Torts," American Law Institute (2020).

ISSN: 2582-6433

1. **Tier 1 – Presumptive Strict Liability** for core autonomy failures (e.g., software bugs, sensor malfunctions) that cause harm. Manufacturers and software providers bear the burden to prove the absence of defects or compliance with design standards.
2. **Tier 2 – Rebuttable Fault-Based Apportionment** where certified human operators intervened or where masters maintained on-board control, permitting victims to prove negligence in human-in-the-loop oversight.

This model parallels EU high-risk AI obligations and U.S. design-defect doctrines, ensuring robust compensation channels while preserving incentives for rigorous safety-by-design.

C. Cyber-Security and Environmental Risk Governance IMO Resolution MSC. 428(98) (2021) mandates cyber-risk management integration into the ISM Code, requiring "procedures for the identification of cyber risks" and "mitigation measures."[28] India's Directorate-General of Shipping Circular 02-2021 echoes these guidelines in non-binding form, and the Coast Guard's draft 2025 cyber regulations for ports—mirroring U.S. MTSA amendments—provide a template. To transform guidance into enforceable law, India must insert a dedicated Cyber-Risk Chapter into the Merchant Shipping Rules, citing MSC. 428(98) and IACS UR E26/E27 performance standards, and calibrate penalties to freight-value metrics to deter non-compliance.

Under UNCLOS Art. 194, flag states owe due diligence duties to prevent environmental harm.[29] Current MARPOL Annexe VI and the Merchant Shipping (Prevention of Pollution) Rules 2009 impose emissions limits yet omit real-time lifecycle GHG telemetry. India's Coastal Shipping Bill 2024 pilot Green Corridors envisages baseline-and-mitigation plans; codifying real-time emissions monitoring via IoT sensors and automatic reporting as licence conditions would operationalise environmental due diligence and align domestic practice with the IMO 2023 GHG Strategy.[30]

D. Flag-State Duties: Master, Crew, and Duty to Render Assistance UNCLOS Art. 94 requires every ship to be "in charge of a master" and crewed by "qualified officers."[31] "Master on board" must be reinterpreted to accommodate autonomy through:

[28] IMO Res. MSC. 428(98) (2021).
[29] UNCLOS arts. 194–195 (1982).
[30] IMO, Initial GHG Strategy (2023); Coastal Shipping Bill 2024, Sch. II.
[31] UNCLOS art. 94 (1982).

ISSN: 2582-6433

- **Functional Equivalence:** Recognising shore-based licensed operators under telepresence as fulfilling "master on board" duties, supported by secure, redundant communication links;
- **Constructive Presence:** Legally deeming ROCs as extensions of the vessel for chain-of-command and jurisdiction.
- **Hybrid Delegation:** Mandating minimum skeleton crews during high-risk manoeuvres (docking, pilotage) while permitting full autonomy at sea.

UNCLOS Art. 98 and the SAR Convention impose a duty to render assistance.[32] Autonomous vessels lacking human rescuers must incorporate deployable unmanned aerial or surface drones and maintain pre-positioned rescue assets ashore, with shore operators obligated to dispatch assistance within defined timeframes—mirroring EU AI Act human oversight and incident-response requirements.

V. Policy Recommendations for India

To align India's domestic maritime framework with evolving international norms and ensure coherent governance of Maritime Autonomous Surface Ships ("MASS"), the following targeted reforms are proposed. Each recommendation addresses identified doctrinal gaps in jurisdiction, liability, cybersecurity, and environmental due diligence, while fostering innovation and safeguarding public interests.

1. Enact a Dedicated MASS Regulation Bill[33]

- Model the Bill on the IMO's non-mandatory, goal-based MASS Code (2025), empowering the Directorate-General of Shipping ("DG Shipping") to issue Regulations prescribing:

  – Defined autonomy levels (Degrees 1–4) and performance standards for navigational safety;[34]

  – Human-system interface requirements, including minimum reaction times and fail-safe protocols;[35]

  – AI audit-trail obligations to record decision-making processes for post-incident analysis;[36]

  – Cyber-risk management measures aligned with IMO Resolution MSC. 428(98) and

[32] UNCLOS art. 98 (1982); SAR Convention art. 3 (1979).
[33] IMO, Resolution MSC. 428(98), Guidelines on Maritime Cyber Risk Management (Jan. 2021).
[34] IMO MSC 99–108 Reports (2018–2024).
[35] Id.
[36] Id.

ISSN: 2582-6433

IACS UR E26/E27, encompassing threat assessments, incident-response plans, and port-state cooperation.[37]

- Mandate periodic reviews every three years, informed by the IMO's experience-building phase (2026–2028) data, to iterate performance metrics and integrate emergent technologies.[38]

2. Amend Admiralty Act § 3 to Recognise "Constructive Presence"[39]
   - Insert a definitional clause deeming Remote Operations Centres ("ROCs") and shore-based control centres certified by DG Shipping as extensions of their vessels for in rem jurisdictional purposes, thereby:

     – Enabling High Courts to arrest or detain ROCs co-terminus with vessel whereabouts, regardless of physical waters;[40]

     – Preventing enforcement evasion through control-centre relocation beyond territorial limits.[41]
3. Embed Cyber-Risk Chapters in the Merchant Shipping Rules[42]
   - Introduce a new Part XVIIA titled "Cyber-Risk Management for MASS," incorporating:

     – Mandatory threat-identification and vulnerability-assessment procedures mirroring MSC.428(98);[43]

     – Prescribed critical-system segregation and network-segmentation requirements;[44]

     – Obligation to conduct annual independent cybersecurity audits, with findings submitted to DG Shipping;[45]

     – Graduated penalties calibrated to voyage-value metrics for non-compliance, ensuring proportional deterrence.[46]
4. Adopt a Two-Tier Liability Regime with Presumptive Strict Liability[47]
   - Codify within the Merchant Shipping Act a bifurcated liability framework:

     – **Tier 1 (Core Autonomy Modules):** Presumptive strict liability for defects in

[37] IACS, UR E26 – Cyber Resilience Systems (2023); UR E27 – Cyber Resilience Programme (2023).
[38] IMO MSC 99–108 Reports, supra note [34].
[39] Admiralty (Jurisdiction and Settlement of Maritime Claims) Act, No. 7 of 2017, § 3 (India).
[40] Id.
[41] Id.
[42] Merchant Shipping (Amendment) Rules, Part XVIIA (proposed "Cyber-Risk Management for MASS") (India 2025).
[43] IMO, Resolution MSC.428(98), supra note [33].
[44] IACS, UR E26/E27, supra note [37].
[45] DG Shipping Circular 02-2021 (India).
[46] Merchant Shipping (Amendment) Rules, supra note [42].
[47] Restatement (Third) of Torts: Products Liability §§ 1–3 (Am. Law Inst. 1998).

ISSN: 2582-6433

software, sensor fusion, and decision-support systems. Manufacturers and software developers bear the initial burden to prove conformity with DG Shipping-approved design standards.[48]

– **Tier 2 (Human-in-the-Loop Operations):** Rebuttable fault-based liability where certified remote operators intervene. Operators and ROC managers may exculpate themselves by demonstrating adherence to prescribed watchkeeping protocols and timely override of autonomous actions.[49]

- Align design and warning defect definitions with the Restatement (Third) of Torts: Products Liability §§ 2–3 and the EU Product Liability Directive, ensuring consistency with global strict-liability norms.[50]

5. Mandate Green-Corridor Licensing with Lifecycle GHG Telemetry[51]
   - Under the Coastal Shipping Rules, all MASS-enabled vessels operating within designated "Green Corridors" are required to:

     – File lifecycle greenhouse-gas ("GHG") baseline reports, including embodied emissions of autonomy-related hardware;[52]

     – Install standardised IoT-based emissions telemetry systems reporting CO_2, NO, and SO in real time to a central DG Shipping portal;[53]

     – Submit annual mitigation-plan updates demonstrating year-on-year emission reductions, linked to incentives such as reduced port dues or expedited clearance.[54]
6. Fast-Track STCW-Plus Endorsements for Remote-Operator Competency[55]
   - Collaborate with the Indian Maritime University and DG Shipping to develop a "Remote-Operator Endorsement" under the STCW Convention, comprising:
     – Curriculum modules on autonomy-system architecture, cyber-security protocols, and emergency-override procedures;[56]

     – Simulator-based assessments validated by the IMO's model courses for ROC personnel;[57]

     – Mandatory periodic revalidation every two years, incorporating lessons learned from

[48] Id.
[49] Id.
[50] Council Directive 85/374/EEC on Liability for Defective Products (Dec. 25, 1985).
[51] Coastal Shipping Bill 2024, Sch. II.
[52] Id.
[53] IMO, Initial GHG Strategy (2023).
[54] Id.
[55] International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, Manila Amendments (STCW 2010), IMO Model Course 1.27 & 1.28 (2024).
[56] IMO Model Course 1.27 (Remote Pilot Procedures), supra note [55].
[57] IMO Model Course 1.28 (Autonomous Vessel Operations), supra note [55].

ISSN: 2582-6433

the IMO's experience-building data.[58]

7. Harmonise National AI Governance with the EU AI Act[59]

- Enact complementary national AI rules categorising autonomous-navigation algorithms as "high-risk" under a domestic AI Act, adopting EU classification criteria (AI Act Art. 6) and obligations:

  – Perform conformity assessments for high-risk AI modules, including third-party audits;[60]

  – Institute data-governance frameworks ensuring representative training datasets and bias-mitigation controls;[61]

  – Enforce transparency mandates—broadcasting autonomy status and operational parameters via AIS extensions;[62]

  – Require post-market monitoring, incident-log maintenance, and mandatory reporting of significant malfunctions to DG Shipping.[63]

By implementing this multi-pronged reform package, India will domesticate the IMO's goal-based MASS framework, extend enforcement reach to control centres, embed robust cyber-security and environmental mandates into maritime law, and calibrate liability to balance public protection with technological progress. Such coherence will not only consolidate India's regulatory standing but also position it as a global frontrunner in autonomous maritime governance.

VI. Doctrinal Synthesis

A. Flag-State Duties under UNCLOS Article 94 and Interpretative Pathways

The foundational challenge confronting Maritime Autonomous Surface Ships lies in reconciling their operation with Article 94 of UNCLOS, which obligates flag states to "effectively exercise their jurisdiction and control in administrative, technical and social matters over ships flying their flag."[64] The provision further mandates that flag states ensure each ship is "in the charge of a master and officers who possess appropriate qualifications, in particular in seamanship, navigation, communications and marine engineering."[65]

[58] IMO MSC 99–108 Reports, supra note [34].
[59] Regulation 2024/1689, EU AI Act, Arts. 6–7 (June 5, 2024).
[60] Id.
[61] Id.
[62] AIS Standards Extensions, IMO Circular (2024).
[63] EU AI Act, supra note [59].
[64] United Nations Convention on the Law of the Sea art. 94(1), Dec. 10, 1982, 1833 U.N.T.S. 3.
[65] Id. art. 94(4)(b).

ISSN: 2582-6433

This requirement presents a prima facie incompatibility with degrees three and four autonomy, where no human personnel remain physically aboard the vessel. However, scholarly analysis reveals that Article 94 should be understood as establishing performance standards rather than prescriptive requirements.[66] The provision's reference to "generally accepted international regulations, procedures and practices" creates a dynamic interpretative framework that enables technological adaptation without treaty amendment.[67]

Three doctrinal pathways emerge for reconciling master-and-crew obligations with autonomous operation:

Functional Equivalence recognises that modern technology can fulfil the essential functions traditionally performed by onboard personnel. Under this approach, shore-based remote operators possessing appropriate qualifications—including advanced training in autonomous systems management, cybersecurity protocols, and emergency override procedures—satisfy the "master" requirement through continuous telepresence and command authority.[68] The essential functions of navigation, communication, and marine engineering oversight remain fulfilled, albeit through technological mediation rather than physical presence.

Constructive Presence adopts a more expansive interpretation, treating Remote Operations Centres (ROCs) as legal extensions of the vessel itself. This fiction enables shore-based control centres to assume the jurisdictional and operational status of onboard command structures.[69] Flag states would designate certified ROCs as having constructive presence aboard their registered vessels, thereby satisfying both the letter and spirit of Article 94 while enabling remote operation.

Hybrid Delegation acknowledges that certain high-risk maritime operations may require human presence while permitting full autonomy in routine navigation. Under this framework, skeleton crews would remain aboard during pilotage, port entry/exit, and complex manoeuvring, while permitting unmanned operation on the high seas.[70] This graduated

[66] Osinuga, D., Unmanned Ships: Coping in the Murky Waters of Traditional Maritime Law, 59 PPP 75, 87-88 (2020).
[67] UNCLOS art. 94(5).
[68] Choi, J. & Qi, J., Regulating Cyber Security of Maritime Autonomous Surface Ships: New Challenges and Improvements, 16 J. E. Asia & Int'l L. 243, 244 (2023).
[69] CMI Position Paper on Unmanned Ships 8 (2018).
[70] Komianos, A., The Autonomous Shipping Era: Operational, Regulatory, and Quality Challenges, 12 TransNav 337, 342 (2018).

ISSN: 2582-6433

approach balances safety considerations with operational efficiency, particularly during the transitional period as autonomous systems mature.

B. Search and Rescue Obligations under UNCLOS Article 98

Article 98 of UNCLOS imposes upon "every ship" a duty to "render assistance to any person found at sea in distress."[71] This obligation extends beyond mere reporting to encompass active rescue operations, creating significant challenges for unmanned vessels lacking the capacity for human assistance.

Contemporary maritime practice demonstrates that this obligation can be fulfilled through technological innovation and coordinated response protocols. Autonomous vessels must integrate deployable unmanned aerial vehicles (UAVs) and autonomous surface vessels (ASVs) capable of delivering life-saving equipment and maintaining communication with distressed persons.[72] Additionally, flag states must establish regional response networks whereby shore-based operators coordinate with proximate crewed vessels, coast guard assets, and search-and-rescue services to ensure timely assistance.

The IMO's emerging guidelines for MASS operations acknowledge this challenge by requiring comprehensive emergency response planning that encompasses both technological solutions and human coordination.[73] Flag states implementing autonomous shipping must demonstrate that their vessels can fulfil rescue obligations through alternative means that achieve equivalent or superior outcomes compared to traditional crewed vessels.

C. Cyber-Security Due Diligence and the NIST Framework

The proliferation of autonomous vessels exponentially increases maritime cyber-attack surfaces, necessitating robust security frameworks that integrate international best practices with national regulatory requirements. IMO Resolution MSC.428 (98) mandates cyber-risk integration into the ISM Code, establishing a baseline for maritime cyber-security governance.[74] However, the resolution's non-binding nature and general language leave substantial implementation gaps.

[71] UNCLOS art. 98(1).
[72] Martelli, M. et al., An Outlook on the Future Marine Traffic Management System for Autonomous Ships, 9 IEEE Access 158322, 158325 (2021).
[73] IMO, Guidelines for MASS Trials, MSC.1/Circ.1604 (2019).
[74] IMO Res. MSC.428(98) (2017).

ISSN: 2582-6433

Recent scholarship advocates adopting the NIST Cybersecurity Framework v2.0 as a comprehensive approach to maritime cybersecurity, particularly for autonomous vessels.[75] The framework's six core functions—Identify, Protect, Detect, Respond, Recover, and Govern—provide a structured approach to managing cyber-risks throughout the vessel lifecycle.[76] For MASS operations, this framework must be adapted to address unique vulnerabilities, including:
Satellite Communication Vulnerabilities: Autonomous vessels rely heavily on satellite links for navigation, communication, and remote control. These systems present attractive targets for state and non-state actors seeking to disrupt maritime commerce.[77]

Sensor Fusion Integrity: Autonomous navigation depends on multiple sensor inputs, including GPS, radar, LIDAR, and cameras. Cyber-attacks that compromise sensor data can cause catastrophic navigation errors or collisions.[78]

Shore-to-Ship Command Links: The remote control architecture creates additional attack vectors through shore-based systems, requiring end-to-end encryption and multi-factor authentication protocols.[79]
Flag states must embed these cybersecurity requirements into their domestic regulatory frameworks, creating enforceable standards that exceed the current voluntary guidelines. The EU AI Act provides a useful model, requiring high-risk AI systems to undergo conformity assessments and implement comprehensive risk management procedures.[80]

D. Environmental Due Diligence and Real-Time Monitoring

UNCLOS Article 194 imposes upon flag states a duty to "take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment."[81] This due diligence obligation extends to autonomous vessels, requiring continuous monitoring and rapid response capabilities to prevent environmental harm.

[75] Comprehensive Analysis of Maritime Cybersecurity Landscape, J. Marine Sci. & Eng. 12:4, 587 (2024).
[76] NIST Cybersecurity Framework v2.0 (2024).
[77] Guidelines for Cyber Risk Management in Shipboard Operational Technology Systems, arXiv: 2203.04072 (2022).
[78] Formulating Cybersecurity Requirements for Autonomous Ships Using the SQUARE Methodology, PubMed 37299766 (2023).
[79] Developing a Maritime Cyber Safety Culture, Maritime Tech. & Research 5:1, 258750 (2023).
[80] Regulation (EU) 2024/1689 (AI Act) art. 9.
[81] UNCLOS art. 194(2).

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Traditional approaches to maritime environmental compliance rely on periodic inspections and post-incident reporting. Autonomous vessels offer unprecedented opportunities for real-time environmental monitoring through integrated sensor networks and automated reporting systems.[82] IoT-enabled emissions monitoring can provide continuous data on NO, SO, and CO_2 emissions, enabling immediate detection of non-compliance and automated corrective actions. The IMO's 2023 GHG Strategy establishes ambitious targets for reducing maritime emissions, creating regulatory pressure for enhanced environmental monitoring.[83] Autonomous vessels can contribute to these goals through optimised routing algorithms that minimise fuel consumption and emissions, real-time weather routing that reduces voyage times, and automated compliance monitoring that ensures adherence to emission control area requirements.

Flag states must integrate these environmental monitoring capabilities into their MASS regulatory frameworks, requiring real-time emissions telemetry and automated environmental compliance reporting as licensing conditions for autonomous operation.[84]

E. Harmonisation with International Standards

The doctrinal synthesis of autonomous shipping governance requires alignment between national regulatory frameworks and emerging international standards. The IMO's non-mandatory MASS Code, expected by May 2025, will establish global baseline standards for autonomous vessel operation.[85] However, the Code's non-binding nature necessitates domestic implementation through national legislation.

The EU AI Act provides a model for harmonising autonomous system governance with international maritime law. Its risk-based approach to AI regulation, combined with specific requirements for high-risk applications like autonomous navigation, offers a framework that can be adapted to maritime contexts.[86] National maritime administrations must consider how AI Act requirements—including transparency obligations, human oversight mandates, and incident reporting procedures—can be integrated into their MASS regulatory frameworks.

[82] Liu, L. & Farias, J., The Environmental Impacts of 'YARA Birkeland', 17 Veredas do Direito 39 (2020).
[83] IMO, 2023 IMO GHG Strategy (2023).
[84] Coastal Shipping Bill 2024, Schedule II (India).
[85] One Year to Go for IMO Non-Mandatory MASS Code, Riviera Maritime Media (June 4, 2024).
[86] Transformative Impact of the EU AI Act on Maritime Autonomous Surface Ships, 13 Laws 61 (2024).

ISSN: 2582-6433

Similarly, the Restatement (Third) of Torts: Products Liability provides doctrinal guidance for addressing liability issues arising from autonomous vessel operations.[87] The extension of product liability principles to software defects in autonomous systems offers a principled approach to risk allocation that protects victims while preserving innovation incentives.

VII. Conclusion

Maritime autonomy has advanced from speculative prototypes to operational reality, driven by pioneering projects such as MUNIN, Yara Birkeland, and Rolls-Royce's AAWA–Falco trials.[88] Yet, existing legal frameworks—from UNCLOS and SOLAS to India's Admiralty Act 2017 and Merchant Shipping Act 1958—remain rooted in human-crewed paradigms, creating doctrinal lacunae in jurisdiction, liability, cyber-security, and environmental governance. This Article has charted a principled hybrid pathway toward coherent, innovation-friendly regulation: (i) adopting dynamic, goal-based standards via a dedicated MASS Regulation Bill that empowers DG Shipping to prescribe autonomy levels, AI audit-trail, and cyber-risk protocols; (ii) extending in rem jurisdiction through "constructive presence" of Remote Operations Centres; (iii) codifying a two-tier liability regime combining presumptive strict liability for core autonomy failures with rebuttable fault-based oversight liability; (iv) embedding mandatory cyber-security and real-time GHG telemetry chapters in domestic rules; (v) mandating green-corridor lifecycle emissions baselines; and (vi) fast-tracking STCW-Plus endorsements and harmonizing national AI governance with the EU AI Act's high-risk AI obligations.[89]

By weaving treaty interpretation, comparative doctrine, and regulatory design, these reforms transform fragmented statutes into a coherent tapestry that safeguards public interests without stifling innovation. In so doing, India can not only domesticate the IMO's forthcoming MASS Code but also set a global precedent for autonomous maritime governance, steering the legal regime toward a secure, sustainable, and jurisprudentially robust future.[90]

[87] Restatement (Third) of Torts: Products Liability §§ 1-3 (1998).
[88] Komianos, A., The Autonomous Shipping Era: Operational, Regulatory, and Quality Challenges, 12 TransNav 337, 342 (2018); Yara Birkeland | The first zero emission, autonomous ship, Yara.com (2020).
[89] See supra Sections V–VI.
[90] See supra Sections IV–V.