

Anchoring Legal Certainty upon the Liability Ambiguities of Autonomous Vessels under International Maritime Law

Fitri Maharani

Master of Law, Faculty of Law, Gadjah Mada University In Yogyakarta, Indonesia

*Corresponding author:

E-mail: maharaniftr@mail.ugm.ac.id

Abstract.

The emergence of Maritime Autonomous Surface Ships (MASS) technology creates normative ambiguity because the current international legal framework is still human-centric. This research departs from the problematic legal ambiguity regarding MASS in the international maritime law regime and how legal certainty theory views and provides solutions to it. This research aims to analyze the unpreparedness of maritime regulations in reaching the operational reality based on artificial intelligence that separates the locus of control from the physical ship, and formulate the direction of legal reform through the perspective of legal certainty theory. The research method used is normative-doctrinal with a statutory and conceptual approach analyzed qualitatively-deductively. The results of the study indicate the urgency of functional redefinition of the role of the captain and the legal status of the ship, as well as a shift in the paradigm of responsibility from the fault-based liability model to strict liability or product liability due to the risk of systemic failure. This has implications for the demand for restructuring of responsibilities from individual-based to system-based to ensure legal predictability and the effectiveness of flag state control.

Keywords: *Maritime Autonomous Surface Ships, MASS Code, normative ambiguity, legal liability and legal certainty.*

I. INTRODUCTION

Today, the global maritime industry is at a historic turning point with the emergence of autonomous vessel technology, or Maritime Autonomous Surface Ships (MASS) (Kim et al., 2020). While this technological revolution offers the potential to improve operational efficiency and navigational safety, its existence fundamentally challenges the maritime legal order (Kilinc, 2025). The transformation from conventional, human-centric navigation to AI-driven systems has created a gap in the existing international legal infrastructure (Peng et al., 2025). Consequently, there is an urgency to critically evaluate the extent to which existing norms are able to accommodate the unique characteristics of these unmanned vessels (Kilinc, 2025).

In the current international maritime legal order, the 1982 United Nations Convention on the Law of the Sea (UNCLOS) holds a position as a framework convention that establishes the primary obligations for Flag States (Beckman, 2022). Based on Article 92 of UNCLOS, every state is obliged to exercise effective jurisdiction and control over ships flying its flag, primarily in administrative, technical, and social aspects (Lampo, 2022). So far, the regulation of accountability in international maritime law, such as the International Convention for the Safety of Life at Sea (SOLAS), the Convention on International Regulations for Preventing Collision Regulations (COLREGs), and the STCW International Convention on Standards of Training, Certification, and Watchkeeping of Seafarers (STCW), for conventional ship operations relies heavily on the physical presence of qualified captains and crew as responsible legal subjects (Stones, 2017; Beckman, 2022).

The main characteristic of the current ruling regime is the application of the principle of fault-based liability, where historically, as many as 80% to 90% of maritime accidents have been attributed to human error (Wrobel, 2021; Carey, 2023). This means that eyewitness testimony is still the main key in maritime accident investigations to date (Kilinc, 2025). Therefore, the primary foundation for mapping the legal shifts that have occurred is understanding the legal accountability provisions in international maritime law, particularly based on UNCLOS 1982, regarding conventional ship operations (Beckman, 2022).

However, the emergence of MASS with various levels of autonomy challenges the basic assumptions of maritime law, ranging from decision-making assistance to full unmanned autonomy (Kilinc, 2025). Operation of autonomous vessels at levels 3 or 4 is characterized by the transfer of control from the physical bridge to a Remote Operation Center (Peng et al., 2022). This has sparked debate about whether a remote operator can be considered a functional master (de facto master) and the qualifications of that operator (Kilinc, 2025). Furthermore, the artificial intelligence (AI) algorithms and sensor data used in MASS shift the risk profile from human navigational errors, including human error, to systemic failures, software malfunctions, and cyberattacks (Khan et al., 2023).

This incident requires an in-depth analysis of the operational characteristics of autonomous vessels in the application of the concept of legal responsibility in international maritime law, where traditional doctrines are no longer possible to be used as a basis for consideration in reaching the chain of responsibility that currently involves software developers and manufacturers of imitation intelligence systems (Islam, 2025). In implementing the norms of operational responsibility for autonomous vessels, there is a normative ambiguity, where this ambiguity arises after subjective terms such as "good seamanship practices" must be translated into deterministic algorithmic technical standards (Verma et al, 2025). In addition, there is also a legal void during the transition to the MASS Code which is mandatory for implementation in 2032 (Kilinc, 2025).

Previous research has identified the unpreparedness of the human-centric international maritime law regime in responding to MASS developments at levels 3 and 4. (Peng et al, 2025). Other research also links this to the principle of a "genuine link" regarding navigation control to a remote operations center (Parlov, 2025). Nevertheless, this research presents a novelty through a deconstruction of international maritime law related to MASS liability, with its unique analysis lying in the use of Gustav Radbruch's theory of legal certainty. This theory of legal certainty is used to dissect the ambiguity of norms that cause instability in the resilience of international maritime legal instruments in responding to the development of MASS, particularly regarding how subjective terms such as "good seamanship" lose their technical basis when confronted with closed, deterministic algorithms (Alexy, 2021).

This study offers a substantive contribution in the form of a functional redefinition of the role of the master to become a remote operator and a proposed shift in the liability regime from a fault-based model to strict liability or product liability (Peter and Ma, 2025). Furthermore, this study provides legal urgency by mapping the risk of the emergence of "shadow fleets" due to the legal vacuum during the transition period towards the global implementation of the MASS Code in 2032 (Chae, 2024; Rodriguez-Diaz et al., 2025). These findings encourage a radical transformation from a human-centric to a system-centric maritime legal system to ensure legal predictability and the effectiveness of flag state control.

Based on these problems, this research was conducted with 2 (two) main problem formulations. First, "How does the ontological discontinuity between the human-centric international maritime legal regime and the operational characteristics of autonomous vessels trigger normative ambiguity in the attribution of legal responsibility and the redefinition of the functional status of the master?" Second, "How can the deconstruction of traditional liability doctrine through the lens of Gustav Radbruch's theory of legal certainty formulate the direction of legal reform in the regulation of autonomous vessels? This article will formulate the direction of legal reform needed to ensure the safety of navigation and the protection of the marine environment in the future through an evaluation of the conflict between the conventional legal framework and the reality of autonomous technology (Alwan, 2025).

II. METHODS

This study uses a juridical-doctrinal research method to examine the ambiguity in the framework of autonomous vessel liability in the international maritime law regime. A conceptual and legislative approach is used to assess the adequacy of available legal norms. The analysis is based on secondary data, in the form of primary legal materials including major international maritime legal instruments such as UNCLOS 1982, SOLAS 1974, COLREGs 1972, STCW 1978, the Regulatory Scoping Exercise (RSE) and the still-developing draft MASS Code, secondary legal materials in the form of textbooks, scientific journal articles,

research reports from maritime research institutions, and opinions from international maritime law experts related to international maritime law and autonomous shipping technology, and tertiary legal materials including legal dictionaries and legal encyclopedias. Data triangulation is carried out using the theory of legal certainty as a theoretical framework operationalized with three main dimensions, namely norm clarity, predictability, and stability of legal relations, to identify the urgency of norm redefinition. The data were analyzed qualitatively using deductive reasoning, starting from general premises regarding the international maritime legal framework and then applying them to the specific phenomenon of autonomous ship technology development. Furthermore, the findings were analyzed using legal certainty theory to identify ambiguities in the international maritime legal regime regarding the operational reality of autonomous ships. Ultimately, legal solutions can be developed to fill the existing legal gaps.

III. RESULTS AND DISCUSSION

In the contemporary maritime legal order, UNCLOS 1982 serves as a framework convention that mandates the sovereignty and jurisdictional responsibilities of flag States (Beckman, 2022). Based on the fundamental principle in Article 94 of UNCLOS, each flag State bears primary responsibility for ensuring that ships flying its flag comply with international regulations regarding the safety of navigation through a series of routine inspections, adequate communication equipment, and collision prevention, as well as the prevention of shipborne pollution (Ji, 2022; Silalahi and Putri, 2025). Critically, this regime is built on the basic assumption of a human-centric system, where the direct presence of the ship's crew and master is considered a constitutive element in maintaining the safety of navigation (Hawse, 2019).

Furthermore, SOLAS, COLREGs, and STCW, which are technical instruments referenced by UNCLOS through the "reference rules" mechanism, are built on a human-centered system paradigm. An example is Article 39 (2) of UNCLOS, where ships transiting international straits are required to comply with the regulations for preventing collisions at sea regulated through COLREGs (Zhou et al, 2020). Rule 5 in COLREGs requires continuous human sight and hearing lookouts to comprehensively assess the risk of collision (Miyoshi et al, 2021). In conventional ship operations, compliance with these technical standards is the primary measure in determining a ship's seaworthiness (Dadiani, 2018). Overall, the reflection of the balance between Flag State sovereignty and international obligations to maintain the safety and order of ships in the face of unpredictable maritime dynamics, through accredited human control, can be seen through the standards of "good seamanship" (good seamanship practices) as well as the appropriateness of liability arrangements in international maritime law for conventional ships (Sun, 2021; Alwan, 2025).

Based on Article 94 paragraph (4) letter (b) of UNCLOS, a normative standard has been established that every ship must be under the responsibility of a captain and officers who have appropriate qualifications in the fields of nautics, navigation, communications, and ship engineering (Beckman, 2022). The legal subject that bridges public and civil responsibilities in ship operations is an important role held by the ship's captain (Badaruddin et al, 2021). In the traditional legal narrative, the captain is not only the leader of the ship he is riding, but also as the legal agent of the shipowner who is given statutory authority to sign rescue contracts, maintain order, and act as a public notary in emergency situations (Nurtjahjo, 2022). STCW, SOLAS, and other technical conventions emphasize the position of the captain by requiring the captain to always be on the ship's bridge to carry out continuous supervision (Dalaklis et al, 2020). Analytically, the legal responsibilities of a ship's captain include protecting human life at sea, securing cargo, and preventing marine pollution, making the captain ultimately responsible for all navigational decisions (Ji, 2022). Furthermore, the captain's authority is absolute and cannot be interfered with by any party while the ship is at sea, thus functionally making him the primary subject of attribution of public responsibility (Vojković and Milenković, 2020).

The liability regime in conventional maritime law is generally fault-based. This means that determining liability in maritime incidents relies heavily on proving negligence or culpable conduct on the part of the ship's captain or crew (Hawse, 2019). Based on this, the doctrine of vicarious liability (or respondeat superior) plays a crucial role in holding shipowners legally liable for losses caused by the actions of the captain and crew within the scope of their duties (Alwan, 2025). This is supported by historical data

showing that approximately 80% of incidents at sea are caused by human error, thus traditional maritime law prioritizes investigations based on human testimony (Wrobel, 2021; Kilinc, *The Transition...*, 2025).

Determining liability, from a maritime insurance perspective and legal evidence perspective, relies heavily on the doctrine of proximate cause, which is efficient. Courts in various jurisdictions apply the efficiency test to determine whether a loss was caused by a peril covered by the policy or by a specific exclusion (Manopo and Merkin, 2021). In conventional operations, human decisions during the critical period before a maritime accident are the primary source of traceability in the chain of causality (Kilinc, *The Transition...*, 2025). Therefore, the 1982 UNCLOS framework applied to conventional vessels creates a stable legal ecosystem, where responsibility is clearly divided between the administrative responsibility of the flag State and the operational accountability of humans on the high seas (Parlov, 2025). This overall structure ensures high legal predictability through standardized crew qualifications and navigation procedures supervised by accredited human controllers (Manopo and Merkin, 2021). From a legal certainty perspective, international maritime law is well established because it provides stability for all actors in conventional maritime activities (Sholikah, 2020).

Meanwhile, within the legal accountability dimension of autonomous vessels, there is a fundamental disconnect between the existing international maritime law architecture and the current and future technological realities. This ambiguity is apparently not merely a technical issue, but rather a paradigm shift from a human-centered system to one centered on algorithms and data (Kilinc, *The Transition...*, 2025). This normative ambiguity is triggered by a primary factor: the reliance of international maritime law regimes, such as UNCLOS, SOLAS, COLREG, and STCW, on the physical presence of humans on board as the responsible subject (Oyewole, 2021). As human functions in ship operations begin to be replaced by autonomous systems and algorithms, the conceptual foundations of legal subjects, fault, and causal relationships in maritime law become inadequate to explain this new reality, leaving the development and application of MASS technology seemingly untouched by the current international maritime law regime (Agustina, 2021).

Over time, MASS units have been classified into four levels, each with varying degrees of control between humans and autonomous navigation systems. At MASS level 1, the vessel is controlled conventionally, with the captain and crew remaining on board to maintain full control, aided by autonomous navigation tools in the form of a decision support system that automates several processes (Fan et al., 2021). Legally, the consequences remain within conventional boundaries, as the human element remains dominant in ship control (Peng et al., 2025). Instruments such as STCW and SOLAS can still be applied directly without radical interpretation, and fault-based liability can be applied because the "physical presence" requirement is met (Stones, 2017). At MASS level 2, the vessel is controlled remotely, but the captain and crew remain on board to take over control in emergency situations (Liu et al., 2022). Here, disputes begin to arise regarding who actually holds the authority of "master" under Article 94 of UNCLOS—whether it is the physical master or the remote operator (Ji, 2022). At this point, liability becomes a hybrid, involving the interaction of system operational errors and human error (Alwan, 2025).

Meanwhile, at MASS level 3, the vessel is entirely remotely operated and there are no longer any humans on board (Fenton and Chapsos, 2023). This is the point where the conventional legal framework begins to experience a systemic failure in providing legal certainty (Choi, 2023). The STCW explicitly assumes that the master is the absolute "on board" (Ji, 2022). Furthermore, MASS level 4 operates fully autonomously, with the vessel capable of making decisions and taking actions on its own without human intervention (Son and Huh, 2025). In this situation, the presence of the master and crew is no longer necessary for the ship's navigation and is completely removed from the ship. This level represents the most extreme legal disruption, as there is no longer any human intervention in the decision-making cycle. This makes fault-based liability irrelevant. At this point, the law must shift towards strict liability or product liability imposed on ship owners or software developers (Alwan, 2025).

The characteristics of MASS pose a threat to the clarity of norms in legal certainty. In this context, a conceptual shift has occurred regarding the role of the master. In traditional maritime law, the master is the pillar of legal responsibility who must be directly present on board the vessel being controlled (Ji, 2022).

However, the holder of the highest legal authority on MASS level 3 and 4 vessels creates an ambiguous atmosphere, due to decisions regarding autonomous navigation of the vessel by artificial intelligence (AI) or remote controllers. Therefore, debate has arisen regarding whether the remote operator can be considered a master legally, given that the STCW Convention assumes the master is a person “on board” (Feyzioglu and Yorulmaz, 2023). This uncertainty creates risks, especially in emergency situations, where the absolute responsibilities of the master cannot be fulfilled due to geographically separated control systems (Kilinc, “The Transition...”, 2025). Without synchronization between technology and norms, the international maritime legal order will fall into statutory lawlessness (Noviyanti and Mokodompit, 2025).

Furthermore, the principle of a genuine link between the flag state and the vessel, as stipulated in Article 94 of UNCLOS, is also impacted by this normative uncertainty (Parlov, 2025). This uncertainty arises when an autonomous vessel is controlled from the jurisdiction of a state different from the state in which the autonomous vessel is operated (Halog et al., 2025). This raises fundamental questions about the effectiveness of the flag state's administrative, technical, and social jurisdiction if the locus of physical control is beyond the reach of the laws of the home state (Parlov, 2025). In the absence of firm international coordination, this situation can give rise to the existence of autonomous “shadow fleets” that operate outside the reach of international safety and environmental law enforcement, or even engage in other illegal activities. Furthermore, the existence of shadow fleets also presents fundamental challenges to the prevailing maritime legal structure due to regulatory gaps and limitations in maritime law enforcement, thus providing opportunities for individuals or groups who do not comply with applicable international maritime law (Rodriguez-Diaz et al., 2025).

In the current maritime legal regime, UNCLOS serves as the principal regulation governing all aspects of international maritime activities. However, recently, UNCLOS has been the subject of debate regarding its suitability as a core framework for international maritime law in the face of rapidly evolving maritime issues, such as maritime cyberattacks, smuggling of illegal goods by sea, ongoing hijackings, and illegal fishing. This calls for increasing the effectiveness of UNCLOS through enhanced performance of actors and institutions, such as regional governments and United Nations (UN) agencies, in helping to provide a global legal framework to address international maritime security challenges (Bueger et al., 2025).

Furthermore, other problems can also be found in the adopted liability doctrine. Fault-based liability is the doctrine that has been the prevailing maritime legal liability regime to date, where negligence on the part of the captain or crew serves as the basis for attribution of responsibility (Hawse, 2019). The emergence of autonomous ships undermines this model by shifting the cause of accidents from human-caused navigational errors to failures of the autonomous navigation systems onboard. Ambiguity arises when traditional legal doctrine attempts to attribute fault to machines that lack legal personality. This has led to a shift in traditional legal doctrine to “product liability” or “strict liability” for ship owners or developers of technological systems used on ships (Alwan, 2025). This ensures that accident victims still receive compensation even though the cause is an “algorithmic black box,” where the thought process of AI is based on a thought pattern that is beyond human reach and humans themselves cannot intervene in the intentions or nature of the AI (Selbst, 2020; Peng et al., 2025).

Furthermore, there are cyber risks in the form of satellite connectivity and reliance on data networks, which can pose a major threat to MASS operations (Dadiani, 2018). This broadens the concept of seaworthiness to include the cyber resilience of MASS (Suri, 2020). Therefore, failure to implement adequate cybersecurity protocols can result in a vessel being deemed legally unseaworthy (Dadiani, 2018). The high level of ambiguity created by traditional insurance policies, such as Hull & Machinery (H&M) and Protection & Indemnity (P&I), often excludes losses resulting from cyberattacks through clause CL380, thus rendering autonomous vessel operators ineffective in providing protection (Suri, 2020). Therefore, changing international maritime law with a human-centric approach to a system-centric framework that recognizes the interdependence between technology, data, and legal responsibilities across maritime boundaries is very necessary for the massive operation of autonomous ships in the future (Kilinc, “The Transition...”, 2025).

Problems can also be encountered in determining proximate cause in legal and insurance disputes due to the data-driven nature of MASS operations (Suri, 2020). In remote-controlled vessel navigation, the

controlled vessel is considered the same as a vessel with a full crew on board due to the frequency of human activity on board (ship control) carried out from land, so proving the captain's negligence remains the main key to attributing responsibility (Emiliozzi, 2021). Meanwhile, in vessels with fully autonomous control, the cause of accidents shifts to systemic failures such as AI algorithm errors, sensor malfunctions, and even cyberattacks (Zhou et al., 2024). Judges or arbitrators can have difficulty determining whether an accident was caused by a design error or external intervention when the nature of an artificial intelligence algorithm is not made transparent (Selbst, 2020). This requires the availability of international standards regarding data integrity to ensure that digital evidence is permanent and cannot be manipulated after an incident occurs (Kilinc, "Human-Machine...", 2025). In this case, the question arises of how someone can predict the legal consequences of their actions if the proximate cause of an accident is hidden in millions of lines of inaccessible code (Hasibuan et al., 2024). This undermines the predictability aspect of legal certainty.

Fundamentally, there is also ambiguity regarding the identity of MASS as a "ship" (or vessel) under UNCLOS (Hasan, 2022). If an autonomous vessel does not meet the legal criteria for a ship due to the absence of a crew, then international navigation rights such as "innocent passage" or "transit passage" may not be fully enjoyed (Sümer, 2023). Discussions regarding the granting of legal personality to artificial intelligence systems also add another layer of ambiguity to the existing ambiguity, regarding whether legal responsibility should be borne by the shipowner or whether it can be distributed independently among the system entities (Alwan, 2025). The overall ambiguity inherent in these norms stems from the lag in international law compared to the pace of technological innovation (Kilinc, "Artificial...", 2025). As long as instruments such as the MASS Code remain globally mandatory and uniform, the application of legal liability norms to autonomous vessels will remain a gray area, threatening legal certainty in international maritime trade (Ji, 2022).

Based on the series of analyses that have been compiled previously, the study of the legal liability of the autonomous vessel MASS requires a triangulation analysis using the theory of legal certainty to dissect the extent to which the current international maritime legal order is able to provide protection and predictability for maritime stakeholders. Radbruch postulates that the "Idea of Law" consists of a triad of elements that are in tension with each other, namely justice, utility, and legal certainty (Alexy, 2018). In the operational context of MASS, the use of the theory of legal certainty as a theoretical framework becomes urgent because the global maritime legal order today is experiencing systemic instability in maintaining this triad, especially in this case the aspect of legal certainty that demands clarity, stability, and predictability of norms (Bix, 2018).

The theory of legal certainty is one of the most crucial structural foundations in the doctrine of the rule of law, which positions law not merely as a tool of power, but as a rational and measurable system of norms (Shcherbanyuk, 2023). From the perspective of legal philosophy, particularly through the thinking of Gustav Radbruch, legal certainty is seen as one of the three essential elements of the "Idea of Law" (*Idee des Rechts*), alongside justice (*gerechtigkeit*) and expediency or finality (*zweckmäßigkeit*) (Alexy, 2021). Legal certainty has the character of a "constitutive value" because without a minimum level of certainty, a system of norms cannot legitimately be called a legal system (Shcherbanyuk, 2023).

In detail, legal certainty requires that the law be positive, that is, it is established by an authority that has the power to enforce its implementation, in order to end the conflict of subjective views regarding what is considered fair (Wilk, 1950). This theory includes two main temporal dimensions, namely the *ex ante* dimension related to predictability, where legal subjects must be able to calculate the legal consequences of their actions before acting, and the *ex post* dimension related to stability, where decisions of public authorities, especially courts, that have been taken legally may not be changed arbitrarily (Shcherbanyuk, 2023). The operational manifestation of this stability is reflected in the principle of *res judicata*, which states that court decisions that have become legally binding cannot be questioned again in order to maintain peace and legal order (Shcherbanyuk, 2023).

In his discourse, legal certainty is often caught in a dialectic with justice. In the early phase of his thinking, Radbruch emphasized that judges have a professional obligation to uphold positive laws for the sake of certainty, even if those laws are deemed unjust (Alexy, 2021). An analytical shift occurred after

World War II through the "Radbruch Formula," which states that while legal certainty must be prioritized, if the conflict between positive law and justice reaches an intolerable level, then legal certainty must yield to justice (Alexy, 2021). Alexy (2021) supports this by stating that law inherently has a claim to truth, so certainty cannot be completely separated from morality.

Regarding normative ambiguity, it is seen as a direct antithesis and threat to the theory of legal certainty (Sitorus, 2024). From a constitutional perspective, normative ambiguity is considered a qualitative defect because it hinders the uniform application of the law and opens up room for unlimited interpretation by law enforcement officials, which in turn triggers arbitrariness. To achieve legal certainty, norms must be formulated clearly, unambiguously, and without ambiguity, so that individuals can organize their behavior according to expected standards (Shcherbanyuk, 2023).

Analytically, there is a recognition that absolute certainty is often impossible to achieve due to the limitations of language and the inability of lawmakers to predict all future situations (Komeni and Widjajanti, 2024). There is a linguistic paradox: if norms are formulated too rigidly in pursuit of absolute certainty, the law risks becoming an obsolete fossil and failing to adapt to social dynamics. Therefore, the law must remain able to adapt to changing circumstances without sacrificing the essence of certainty itself (Shcherbanyuk, 2023).

The importance of the role of state language is also highlighted in addressing normative ambiguity (Abdillah et al., 2022). Legal certainty is best achieved in a homogeneous linguistic environment, where legal terminology is used consistently to represent the authentic will of the law-makers (Qamar and Djanggih, 2017). In the event of ambiguity in a legal text, the theory of legal certainty places the responsibility on the judicial interpretation process to restore such clarity, while remaining within the legal framework established to protect individuals from arbitrary intervention by power (Shcherbanyuk, 2023). Thus, normative ambiguity in the theory of legal certainty is not merely seen as a technical problem in drafting laws, but as an existential challenge to the integrity and rationality of the legal system itself.

The principle of legal certainty requires clarity, accessibility, and stability of norms that enable legal subjects to predict the consequences of their actions (Shcherbanyuk, 2023). In the conventional maritime ecosystem, this certainty is achieved through the standardization of the roles of the master and crew, as explicitly stipulated in UNCLOS 1982, SOLAS, and STCW. However, the integration of autonomous technology creates ontological challenges to this principle, which can be examined through three dimensions of triangulation.

First, through the dimension of normative clarity, where legal certainty demands that legal drafters strive for unambiguous normative formulation (Shcherbanyuk, 2023). In MASS operations, ambiguity arises because traditional maritime legal instruments such as COLREGs are based on the assumption of human observation through "sight and hearing." When AI algorithms replace the subjective judgment of the master, terms such as "good seamanship" lose their definite technical basis (COLREG, 1982). From the perspective of legal certainty, without the translation of subjective terms into deterministic algorithmic technical standards, the application of norms in MASS accident cases will be arbitrary and violate the principle of legal certainty (Kilinc, "The Transition...", 2025). Legal certainty can only be restored if the term "master" is functionally redefined to include remote operators at the Remote Operation Center (ROC), to ensure a clear endpoint of accountability (Choi, 2023).

Second From a predictability perspective, a shift in the liability regime and digital evidence can be observed. According to Shcherbanyuk (2023), in Radbruch's doctrine of legal certainty, a person must be able to foresee the legal consequences of their behavior. In conventional shipping, predictability of liability is based on the doctrine of measurable fault through human negligence (Kilinc, "The Transition...", 2025). However, the operational characteristics of MASS shift the risk profile toward systemic and algorithmic black box failures, where machine decisions are often non-intuitive (Nugraha et al., 2022). This study found that maintaining a fault-based liability model in MASS would actually diminish legal certainty for victims, due to the difficulty of proving negligence within the software code (Selbst, 2020). Therefore, the transition to strict liability or product liability for AI system manufacturers is a legal imperative to provide certainty of recovery for third parties.

Third, through the dimension of stability, where legal certainty also includes the stability of legal relations guaranteed by state jurisdiction (Shcherbanyuk, 2023). Article 94 of UNCLOS requires the Flag State to exercise effective control over ships, but the separation of the physical locus of control of ships on the high seas from the control center (ROC) in the sovereign territory of another state threatens the principle of "genuine link" as a fundamental element of the principle of freedom of navigation (Kuznietsov, 2021). Triangulation of norm stability indicates a legal vacuum (rechtsvacuum) during the transition period towards the mandatory implementation of the MASS Code in 2032. Without uniform international standards, there is a risk of disorder due to differences in national regulations, which fundamentally contradicts the legal objective of creating social peace and certainty (Shcherbanyuk, 2023).

The lack of clarity regarding the accountability of autonomous vessels is a manifestation of the current legal system's failure to meet the demands for certainty amidst digital disruption (Kilinc, "The Transition...", 2025). As Radbruch's theory suggests, when legal certainty is threatened by uncertainty about "who is responsible," the stability of the global maritime order will be shaken (Alexy, 2021). Therefore, harmonizing autonomous technology with international maritime law through a reinterpretation of maritime subjects and the adoption of uniform technical standards is the only way to restore the spirit of legal certainty on the high seas.

In navigating the disruption of MASS technology, a transformation of the legal architecture is ultimately required, not merely a patchwork, but rather a fundamental and prescriptive legal engineering. As a response to the ontological failure of human-centric maritime law, the theory of legal certainty has become a new window for examining the phenomenon of normative ambiguity and finding a solution. The first solution offered is a functional redefinition of the primary legal subject in shipping, namely the master (Raska et al., 2024). Given that the locus of control on level 3 and 4 autonomous vessels has shifted from the physical bridge to the ROC, international law must explicitly recognize the remote operator as the de facto master, bearing absolute responsibility similar to a conventional master (Kennard et al., 2022). This is crucial to ensure that even though control is geographically separated, the endpoint of public and civil liability remains a clear and definite legal subject to maintain the integrity of the maritime system (Erwin, 2022).

The second solution aims to shift the legal liability paradigm from a fault-based liability model to a strict liability or product liability regime. Given the algorithmic black box phenomenon that makes it difficult to prove human intent or negligence in the form of strings of code, the traditional burden of proof is no longer sufficient for victims of maritime accidents (Putri et al., 2026). By applying strict liability to ship owners or system developers, legal certainty for third parties can be restored without being trapped in the technical complexity of closed algorithms (Juniarso et al., 2026). This transformation also requires an expansion of the concept of seaworthiness, which must now include aspects of cyber resilience, where failure of digital security protocols must be qualified as a form of legal unseaworthiness of a vessel (Suri, 2020).

The third solution, to avoid the risk of the emergence of "shadow fleets" and a legal vacuum during the transition period, requires accelerated mandatory implementation of the MASS Code before 2032 (Badrudin, 2026). This global legal synchronization must be able to translate subjective standards such as "good seamanship" into deterministic technical parameters that can be understood by artificial intelligence, thereby minimizing arbitrary interpretation by law enforcement officials in various jurisdictions (Noviyanti and Mokodompit, 2025). In addition, countries must strengthen the principle of "genuine link" through international coordination that ensures that the effectiveness of flag state control can still reach operators in the ROC even outside their sovereign territory (Parlov, 2025). Through this system-centric approach that recognizes the interdependence of data, technology, and legal responsibility, the spirit of legal certainty on the high seas can be maintained amidst the storm of global autonomization.

IV. CONCLUSION

The current international maritime law regime, whether in UNCLOS, SOLAS, COLREGs, or STCW, has experienced ontological failure due to its human-centric nature, thus creating a legal vacuum and normative ambiguity regarding MASS operations. which separates the physical locus of control from the vessel. Through the lens of Gustav Radbruch's theory of legal certainty, this ambiguity is seen as an

existential threat to global maritime stability, where subjective terms such as "good seamanship" lose their technical basis when faced with deterministic algorithms. As a substantive contribution, this study deconstructs traditional doctrine by offering a system-centric paradigm that redefines the role of the master functionally to the remote operator and shifts the accountability model towards strict liability or product liability to overcome the challenges of algorithmic black boxes. Normatively, it is recommended to accelerate the mandatory implementation of the MASS Code before 2032, expand the concept of "seaworthiness" to include cyber resilience, and strengthen the principle of genuine link to prevent the emergence of "shadow fleets" beyond the reach of the law. As a prescriptive measure, the transformation of the international maritime law architecture from human supremacy to the integration of measurable digital systems is an absolute requirement to ensure predictability and the rule of law in the autonomous oceans of the future.

REFERENCES

- [1]. Abdillah, K., Faridi, M., & Fawahan, L. (2022). Peran Bahasa dalam Konstruksi Hukum di Indonesia. As-Shahifah : *Journal of Constitutional Law and Governance*, 1(2), 117–133. <https://doi.org/10.19105/asshahifah.v1i2.6274>
- [2]. Agustina, B. A. (2021). Hukum Pengoperasian Kapal Nirawak. *Perspektif*, 26(2), 120–128. <https://doi.org/10.30742/perspektif.v26i2.798>
- [3]. Alexy, R. (2018). The Special Case Thesis and the Dual Nature of Law. *Ratio Juris*, 31(3), 254–259. <https://doi.org/10.1111/raju.12215>
- [4]. Alexy, R. (2021). Gustav Radbruch's Concept of Law. In *Law's Ideal Dimension* (pp. 107–118). Oxford University Press. <https://doi.org/10.1093/oso/9780198796831.003.0008>
- [5]. Alwan, A. G. (2025). The Legal System For Smart Ships. *European Scholar Journal (ESJ)*, 6(3). <https://scholarzest.com/index.php/esj/article/view/4973>
- [6]. Badaruddin, B., Renggong, R., & Hasan, Y. A. (2021). Analisis Tanggung Jawab Hukum Nakhoda Terhadap Keselamatan Pelayaran Di Wilayah Kesyahbandaran Utama Makassar. *Indonesian Journal of Legality of Law*, 3(2), 79–87. <https://doi.org/10.35965/ijlf.v3i2.645>
- [7]. Badrudin, A. (2026). Implementasi Kerangka Kerja Regulasi Keamanan Siber Untuk Kapal Otonom (Mass) Guna Mengantisipasi Risiko Ancaman Hibrida Di Era Pelayaran Masa Depan Dalam Pertahanan Negara Di Laut. *Indonesian Maritime Journal*, 13(3), 15. <https://doi.org/10.52307/xr9zan04>
- [8]. Beckman, R. (2022). IMO Seminar on Development of a Regulatory Framework for Maritime Autonomous Surface Ships (MASS). https://wwwcdn.imo.org/localresources/en/OurWork/Safety/PublishingImages/Pages/MASS/04_Robert%20Beckman_The%20implication%20of%20MASS%20on%20the%201982%20United%20Nations%20Convention%20on%20the%20Law%20of%20the%20Sea.pdf
- [9]. Bix, B. H. (2018). Kelsen, Hart, and legal normativity. *Revus*, 34. <https://doi.org/10.4000/revus.3984>
- [10]. Bueger, C., Edmunds, T., & Stockbruegger, J. (2025). UNCLOS under Fire: Recalibrating Maritime Security Governance. *International and Comparative Law Quarterly*, 74(S1), 85–102. <https://doi.org/10.1017/S0020589325101218>
- [11]. Carey, L. (2023). Contractual and Tortious Maritime Liability Regimes and the Introduction of Autonomous Vessels. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4403620>
- [12]. Chae, C.-J. (2024). MASS and IMO Works. In C.-J. Chae & R. Baumler (Eds.), *Maritime Autonomous Surface Ships (MASS) - Regulation, Technology, and Policy: Three Dimensions of Effective Implementation* (pp. 9–27). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-69437-0_2
- [13]. Choi, J. (2023). Legal Status of Remote Operator in Maritime Autonomous Surface Ships (MASS) Under International Law: Who Can be a Ship Master? In E. Y. J. Lee (Ed.), *Revolutionary Approach to International Law: The Role of International Lawyer in Asia* (pp. 1–19). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-7967-5_1
- [14]. Dadiani, D. (2018). Cyber-Security And Marine Insurance. https://commons.wmu.se/all_dissertations
- [15]. Dalaklis, D., Katsoulis, G., Kitada, M., Schröder-Hinrichs, J.-U., & Ölcer, A. I. (2020). A "Net-Centric" Conduct Of Navigation And Ship Management. *Maritime Technology and Research*, 2(2), 90–107. <https://doi.org/10.33175/mtr.2020.227028>

- [16]. Emiliozzi, E. A. (2021). Unmanned Vessels And Civil Liability In The Field Of Maritime Traffic. In A. Caligiuri & S. Pollastrelli (Eds.), *Law and security along the 21st century Maritime Silk Road* (pp. 216–223). <https://u-pad.unimc.it/handle/11393/292829#>
- [17]. Erwin, R. (2022). Tanggung Jawab Negara Untuk Mencegah Terjadinya Kecelakaan Kapal Transportasi Laut Menurut Hukum Internasional Dan Hukum Nasional. *SUPREMASI: Jurnal Hukum*, 4(2), 177–199. <https://doi.org/10.36441/supremasi.v4i2.716>
- [18]. Fan, C., Montewka, J., & Zhang, D. (2021). Towards a Framework of Operational-Risk Assessment for a Maritime Autonomous Surface Ship. *Energies*, 14(13), 3879. <https://doi.org/10.3390/en14133879>
- [19]. Fenton, A. J., & Chapsos, I. (2023). Ships Without Crews: Imo And Uk Responses To Cybersecurity, Technology, Law And Regulation Of Maritime Autonomous Surface Ships (Mass). *Frontiers in Computer Science*, Volume 5-2023. <https://doi.org/10.3389/fcomp.2023.1151188>
- [20]. Feyzioğlu İ. & Yorulmaz M. (2023). Otonom Gemilerin STCW Sözleşmesindeki Mevcut Düzenlemelere Etkisi. *Akıllı Ulaşım Sistemleri ve Uygulamaları Dergisi*, 6(2), 393–424. <https://doi.org/10.51513/jitsa.1297852>
- [21]. Halog, J., Margat, P., & Stadermann, M. (2024). Submarine Infrastructures and the International Legal Framework. *Transactions on Maritime Science*, 13(1). <https://doi.org/10.7225/toms.v13.n01.w16>
- [22]. Hasan, S. (2023). Analysing The Definition Of “Ship” To Facilitate Marine Autonomous Surface Ships As Ship Under The Law Of The Sea. *Australian Journal of Maritime & Ocean Affairs*, 15(3), 268–283. <https://doi.org/10.1080/18366503.2022.2065115>
- [23]. Hasibuan, R. H., Aurelya Jessica Rawung, Denisha M. D. Paranduk, & Fidel Jeremy Wowiling. (2024). Artificial Intelligence In The Auspices Of Law: A Diverge Perspective. *Mimbar Hukum*, 36(1), 111–140. <https://doi.org/10.22146/mh.v36i1.10827>
- [24]. Hawse, T. (2019). Maritime Autonomous Surface Ships – Identifying And Covering The Risks. *Gard*. <https://gard.no/en/insights/maritime-autonomous-surface-ships-identifying-covering-risks/>
- [25]. Islam, M. S. (2025). Navigating Modern Era At Sea: Legal Challenges And Opportunities Of Unmanned And Autonomous Shipping. *AI and Ethics*, 5(3), 2293–2306. <https://doi.org/10.1007/s43681-024-00554-y>
- [26]. Ji, M. (2022). A Study On The Legal Status And Responsibilities Of The Master In Autonomous Vessels: The Case Of General Remote Operators. https://commons.wmu.se/cgi/viewcontent.cgi?article=3080&context=all_dissertations
- [27]. Juniarso, D., Abdillah, J., & Pratama, M. I. W. (2026). Reformasi Kebijakan Pidana Nasional Terhadap Kejahatan Siber Berbasis AI Melalui Pendekatan Hukum Progresif. *Jurnal Impresi Indonesia*, 5(1), 77–88. <https://doi.org/10.58344/jii.v5i1.7355>
- [28]. Kennard, A., Zhang, P., & Rajagopal, S. (2022). Technology And Training: How Will Deck Officers Transition To Operating Autonomous And Remote-Controlled Vessels? *Marine Policy*, 146, 105326. <https://doi.org/10.1016/j.marpol.2022.105326>
- [29]. Khan R.U., Yin J., Wang S., & Gou Y. (2023). Risk Assessment for Autonomous Ships Using an Integrated Machine Learning Approach. *Engineering Proceedings*, 46 (9). <https://doi.org/10.3390/engproc2023046009>
- [30]. Kilinc N.U. (2025). Artificial Intelligence-Supported Autonomous Shipping: A Strategic Model for Commercial Operations, Risk Management, and New Legal Frameworks. *Research Gate*. <https://doi.org/10.13140/RG.2.2.13135.96161>
- [31]. Kilinc N.U. (2025). Human-Machine Interaction, System Safety and Accident Management in Maritime Autonomous Surface Ships (MASS) Operations: A Preliminary Analysis. *Research Gate*. <https://doi.org/10.13140/RG.2.2.25028.95366>
- [32]. Kilinc N.U. (2025). The Transition to Autonomous Ships: Transformation and Proposed Solutions in Marine Insurance and International Law. *Research Gate*. https://www.researchgate.net/publication/394520185_The_Transition_to_Autonomous_Ships_Transformation_and_Proposed_Solutions_in_Marine_Insurance_and_International_Law
- [33]. Kim, M., Joung, T. H., Jeong, B., & Park, H. S. (2020). Autonomous shipping and its impact on regulations, technologies, and industries. *Journal of International Maritime Safety*, Environmental Affairs, and Shipping, 4(2), 17–25. <https://doi.org/10.1080/25725084.2020.1779427>
- [34]. Komeni, W. H., & Widjajanti, E. (2024). Ketidaktepatan Penerapan Hukum Pidana Adat dalam Pasal 2 KUHP Baru: Prespektif Teori Kepastian Hukum. *Innovative: Journal Of Social Science Research*, 4(3), 1051–1059. <https://doi.org/10.31004/innovative.v4i3.10586>
- [35]. Kuznietsov, S. (2021). The “Genuine link” Concept: Is It Possible to Enhance the Strength? *Lex Portus*, 7(6). <https://doi.org/10.26886/2524-101X.7.6.2021.3>

- [36]. Liu, C., Chu, X., Wu, W., Li, S., He, Z., Zheng, M., Zhou, H., & Li, Z. (2022). Human-machine cooperation research for navigation of maritime autonomous surface ships: A review and consideration. *Ocean Engineering*, 246, 110555. <https://doi.org/10.1016/j.oceaneng.2022.110555>
- [37]. Manopo, B., & Merkin QC, R. (2021). A Critical Analysis of Causation Rules in Marine Insurance. *BESTUUR*, 9(2), 101. <https://doi.org/10.20961/bestuur.v9i2.55165>
- [38]. Miyoshi T., Fujimoto S., & Rooks M. (2021). Study of principles in COLREGs and interpretations and amendments COLREGs for maritime autonomous surface ship
- [39]. (MASS). *Transactions of Navigation*, 6(1), 11-18. <https://doi.org/10.18949/jintransnavi.6.1.11>
- [40]. Noviyanti & Mokodompit, E. A. (2025). Regulasi Industri Maritim: Analisis Kebijakan, Tantangan Global, Dan Implikasi Terhadap Keberlanjutan Sektor Pelayaran. *RIGGS: Journal of Artificial Intelligence and Digital Business*, 4(4), 6670–6680. <https://doi.org/10.31004/riggs.v4i4.4411>
- [41]. Nugraha, T. R., Sudirman, A. ., Putro, Y. M., & Nugraha, R. A. . (2022). Maritime Autonomous Surface Ship (MASS): Tantangan dan Peluang Kemaritiman Masa Depan. *Media Iuris*, 5(1SpecialIssue), 149–172. <https://doi.org/10.20473/mi.v5i1SpecialIssue.38307>
- [42]. Nurtjahjo, A. (2022). Rekonstruksi Regulasi Tanggung Jawab Pekerja Kapal Dalam Mewujudkan Perlindungan Hukum Kepada Pengusaha Berbasis Nilai Keadilan. <https://repository.unissula.ac.id/30927/1/10302000012.pdf>.
- [43]. Oyewole, O. O. (2021). Navigating The Waters: International Law, Environment And Human Rights. *PETITA: Jurnal Kajian Ilmu Hukum Dan Syariah*, 6(1), 1–12. <https://doi.org/10.22373/petita.v6i1.115>
- [44]. Parlov, I. (2025). Remotely Controlled Maritime Autonomous Surface Ships (MASS), the “Genuine Link” Requirement, and the “Effectiveness” of Flag State Jurisdiction: Key Problems and Prospects. *Ocean Development & International Law*, 56(2), 214–231. <https://doi.org/10.1080/00908320.2025.2474551>
- [45]. Peng, Y., Han, X., Ye, Y., & Fan, R. (2025). From National Rules to Global Norms: Aligning China’s L2 Autonomous Ship Regulations with the IMO MASS Code. *Laws*, 14(5), 65. <https://doi.org/10.3390/laws14050065>
- [46]. Peter, M. M., & Ma, M. (2025). Tortious Liability For Autonomous Marine Vehicle Collisions: A Suggestive Move From Fault-based To Strict Liability. *Ocean & Coastal Management*, 269, 107781. <https://doi.org/10.1016/j.ocecoaman.2025.107781>
- [47]. Putri, E. H., Puanandini, D. A., & Ridwan, R. (2026). Disrupsi Kecerdasan Buatan terhadap Prinsip Mens Rea dalam Tindak Pidana Telematika: Tantangan Penentuan Niat Jahat Pada Sistem AI Otonom. *Jurnal Pendidikan Tambusai*, 10(1), 3636–3645. <https://doi.org/10.31004/jptam.v10i1.36644>
- [48]. Qamar, N., & Djanggih, H. (2017). Peranan Bahasa Hukum dalam Perumusan Norma Perundang-undangan. *Jurnal Ilmiah Kebijakan Hukum*, 11(3), 337–347. <https://doi.org/10.30641/kebijakan.2017.V11.337-347>
- [49]. Raska, P. W., Wisudawan, I. G. A., & Fitrahadi, K. F. (2024). Tanggung jawab nahkoda kapal terhadap keselamatan penumpang. *Commerce Law*, 4(2), 331–341. <https://doi.org/10.29303/commercelaw.v4i2.5106>
- [50]. Rodriguez-Diaz, E., Alcaide, J. I., & Endrina, N. (2025). Shadow Fleets: A Growing Challenge in Global Maritime Commerce. *Applied Sciences*, 15(12), 6424. <https://doi.org/10.3390/app15126424>
- [51]. Selbst A. D. (2020). Negligence and AI’s Human Users. *Boston University Law Review*, 100(4), 1315-1376.
- [52]. Shcherbanyuk, O., Gordieiev, V., & Bzova, L. (2023). Legal Nature Of The Principle Of Legal Certainty As A Component Element Of The Rule Of Law. *Juridical Tribune*, 13(1), 21–31. <https://doi.org/10.24818/TBJ/2023/13/1.02>
- [53]. Sholikah, D. I. (2020). Analisis Penyelesaian Perbatasan Laut Antara Peru dengan Chili yang Diselesaikan Oleh Mahkamah Internasional (ICJ). *Jurnal Hukum Lex Generalis*, 1(1), 25–34. <https://doi.org/10.56370/jhlg.v1i1.195>
- [54]. Silalahi W. & Putri M. (2025). Konsep Ekstrateritorialitas Kapal Berbendera Indonesia Dalam Perspektif Unclos 1982: Implikasi Terhadap Wilayah Negara, Pertahanan, Dan Keimigrasian. *Nusantara : Jurnal Ilmu Pengetahuan Sosial*, 12(10). <https://doi.org/10.31604/jips.v12i10.2025.3927-3937>
- [55]. Sitorus, H., Manik, A. Y. S., Aulia, A. R., Desinta, Aqila, Z. N., Saragih, R. R., Herlinda, Nababan, R., & Ibrahim, M. (2024). Analisis Yuridis terhadap Prinsip Kejelasan dan Kepastian Hukum dalam Peraturan Perundang-Undangan : Studi Kasus Uu No. 12 Tahun 2011. *Civics Education and Social Science Journal (CESSJ)*, 6(2), 231–242. <https://doi.org/10.32585/cessj.v6i2.6411>
- [56]. Son, U., & Huh, J.-H. (2025). A Survey of Cyber Security for Maritime Autonomous Surface Ships: Opportunities, Challenges, and Future Directions. *IEEE Transactions on Intelligent Transportation Systems*, 26(6), 7343–7361. <https://doi.org/10.1109/TITS.2025.3560809>

- [57]. Stones, H. (2017). Safely Navigating The Oceans With Unmanned Ships. Weintrit, Adam (ed.) In *Marine Navigation: Proceedings of the 12th International Conference on Marine Navigation and Safety of Sea Transportation (TransNav 2017)*. CRC Press. <http://dx.doi.org/10.1201/9781315099132-43>.
- [58]. Sumer, M. (2023). Overcoming the legal challenges of Maritime Autonomous Surface Ships (MASS) and compliance with UNCLOS and SOLAS. In P. Leucci & I. Vianello (Eds.), *Ascomare Yearbook On The Law Of The Sea (Vol. 3, pp. 149–178)*. Ascomare. <https://doi.org/10.26481/dis.20230411ms>
- [59]. Sun B. (2021). In The Context Of Unmanned Vessels: Obstacles To The Application Of COLREGs And Suggestions For Its Amendments. https://commons.wmu.se/msem_dissertations/425/
- [60]. Suri M. (2020). Autonomous Ships And The Proximate Cause Conundrum - A Maritime And Insurance Law Tango. *SSRN Electric Journal*, 51(2). <https://doi.org/10.2139/ssrn.4910005>
- [61]. Verma, S., Varghese, D., Treloar, A. A., Hunter, A., & Tamaddoni-Nezhad, A. (2025). Resolving Legal Ambiguities for Safe MASS Navigation: A Socio-Technical Approach Using Human-Machine Learning. *OCEANS 2025 - Great Lakes*, 1–10. <https://doi.org/10.23919/OCEANS59106.2025.11245108>
- [62]. Vojković, G., & Milenković, M. (2020). Autonomous Ships And Legal Authorities Of The Ship Master. *Case Studies on Transport Policy*, 8(2), 333–340. <https://doi.org/10.1016/j.cstp.2019.12.001>
- [63]. Wilk K. (1950). *The Legal Philosophies of Lask, Radbruch, and Dabin*. Cambridge: Harvard University Press.
- [64]. Wróbel, K. (2021). Searching For The Origins Of The Myth: 80% Human Error Impact On Maritime Safety. *Reliability Engineering & System Safety*, 216, 107942. <https://doi.org/10.1016/j.res.2021.107942>
- [65]. Zhou, X.-Y., Huang, J.-J., Wang, F.-W., Wu, Z.-L., & Liu, Z.-J. (2020). A Study of the Application Barriers to the Use of Autonomous Ships Posed by the Good Seamanship Requirement of COLREGs. *Journal of Navigation*, 73(3), 710–725. <https://doi.org/10.1017/S0373463319000924>
- [66]. Zhou, Y., Liu, Z., Wang, X., Xie, H., Tao, J., Wang, J., & Yang, Z. (2024). Human errors analysis for remotely controlled ships during collision avoidance. *Frontiers in Marine Science*, 11. <https://doi.org/10.3389/fmars.2024.1473367>