

Impact of Autonomous Ships on Safety of Navigation

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المستخلص

يستعرض البحث الإمكانيات التحويلية للسفن البحرية ذاتية القيادة في العمليات البحرية، مع التركيز على الأبعاد التكنولوجية، التشغيلية والسلامة. يتناول البحث مفهوم السفن ذاتية القيادة ومستويات استقلاليتها، التحديات والمخاطر. وتحدد الدراسة مشكلات بحثية رئيسية تشمل نقاط الضعف التكنولوجية، مثل أعطال أجهزة الاستشعار، وتهديدات الأمن السيبراني، والأخطاء الخوارزمية؛ والمخاطر الناشئة عن بيئات الملاحة المختلطة التي تشمل السفن ذاتية القيادة والسفن المأهولة؛ والثغرات التنظيمية والقانونية التي تعيق التكامل للأمن للتقنيات ذاتية القيادة. بالإضافة إلى ذلك، تُشدد الدراسة على ضرورة توفير تدريب متخصص للبحارة لإدارة هذه الأنظمة الناشئة. يهدف البحث إلى تحليل هذه التحديات والمخاطر بشكل شامل، مع تقييم التطورات في تقنيات سلامة الملاحة. تجمع المنهجية بين مراجعة الأدبيات، وتحليل المخاطر، وتقييم قائم على المسح لتأثير السفن ذاتية القيادة على سلامة الملاحة.

يبرز البحث ضرورة الرقابة البشرية، خاصة في حالات الطوارئ، ويبرز أهمية التعاون بين الإنسان والآلة كحل عملي لتعزيز سلامة الملاحة. كما يناقش الجهود التنظيمية الدولية، خصوصاً دور المنظمة البحرية الدولية في وضع أطر قانونية وأمنية لتعزيز الثقة في السفن ذاتية القيادة. وبناءً على هذه النتائج، يقترح البحث اعتماد نهج هجين يجمع بين الأتمتة والإشراف البشري لضمان التكامل للأمن والفعال لهذه التكنولوجيا في البيئة البحرية.

Abstract

The research explores the transformative potential of autonomous surface vessels in maritime operations, focusing on technological, operational, and safety dimensions. The study addresses the concept of autonomous ships and their levels of autonomy, identify challenges and risks. The study identifies key research problems including technological vulnerabilities such as sensor failures, cybersecurity threats, and algorithmic errors; risks arising from mixed navigation environments involving autonomous and crewed vessels; and regulatory and legal gaps that hinder the safe integration of autonomous technologies. Additionally, the need for specialized training for seafarers to manage these emerging systems is emphasized. The research aims to analyze these challenges and risks comprehensively while evaluating advancements in navigation safety technologies. The methodology combines a literature review, risk analysis, and a survey-based evaluation of autonomous ships' impact on navigational safety.

The research emphasizes the critical role of human oversight, especially during emergencies, and advocates for human-machine collaboration as a practical solution to enhance navigational safety. Additionally, it reviews international regulatory efforts, particularly those by the International Maritime Organization (IMO), aimed at establishing legal and cybersecurity frameworks to build trust in autonomous vessels. Based on these findings, the study recommends adopting a hybrid approach that combines automation with human supervision to ensure the safe and effective integration of autonomous maritime technologies in the maritime domain.

Keywords: Concept of Autonomous Ships, Level of Autonomy, Challenges and Risks Faced Autonomous Ships, Effects of Autonomous Ships on Navigational Safety

1- Introduction

The maritime industry is experiencing a significant transformation with the emergence and adoption of Maritime Autonomous Surface Ships (MASS). These vessels, equipped with advanced artificial intelligence (AI), sensor technologies, and automated systems, offer the potential to revolutionize traditional navigation by improving operational efficiency and substantially reducing human error, which historically accounts for approximately 80% of maritime accidents (Rothblum, 2021). Autonomous ships address these vulnerabilities through automated decision-making and real-time data analysis (Kim et al., 2022; Virtue Marine, 2025).

However, integrating autonomous vessels into existing navigational frameworks presents complex challenges. Key concerns include the interaction between autonomous and manned ships in mixed traffic, which may lead to communication barriers, differing situational awareness, and conflicting decision-making processes (Lützhöft and Dekker, 2002; Munin, 2025). The interpretation and application of International Regulations for Preventing Collisions at Sea (COLREGs) become increasingly complicated when coordinating actions between human operators and autonomous systems. Additionally, technical vulnerabilities such as sensor failures, cybersecurity threats, and algorithmic malfunctions pose further risks to navigation safety (Kim et al., 2022; IMO, 2025; Gad, 2025).

This paper critically analyzes the impact of autonomous ships on navigation safety, focusing on their technological capabilities, operational challenges, and regulatory issues. Key topics include sensor reliability, collision avoidance, cybersecurity, emergency response, and risk management in mixed traffic. It examines current autonomy approaches, such as remote shore control and fully autonomous systems, identifying technical and non-technical barriers. The study emphasizes the need for collaboration among industry stakeholders to achieve safe, efficient, and sustainable maritime navigation in an increasingly automated future.

2- Importance of the research

Research has its special significance as it is likely that autonomous ships will eventually take over the current fleet in the expected future. The research considers and attempts to answer very important questions which revolve around the future of autonomous ships. It will consider how

ships operate and navigate safely and the feasibility of autonomous ships in terms of economic, legal and environmental considerations. It also looks at how trade unions and several national and international regulations pose barriers to autonomous vessels.

This research explores the transformative effects of MASS on navigation safety, a key concern in the maritime industry. It also analyses the regulatory and operational challenges of integrating autonomous vessels into global shipping. The study highlights the urgent need for updated regulations and specialized training for seafarers to effectively manage intelligent navigation systems. These findings provide essential guidance for policymakers and industry stakeholders, helping them balance technological innovation with safety and supporting the secure adoption of MASS to minimize risks and maximize benefits for global maritime operations.

3- Research Problem

The transition to MASS introduces substantial challenges and risks to navigation safety in the shipping industry. Autonomous ships depend on advanced technologies such as sensors, collision avoidance systems, and automated decision-making algorithms, which are vulnerable to sensor failures, cybersecurity threats, and algorithmic errors, increasing the risk of accidents. Mixed navigational environments, where autonomous vessels interact with conventionally crewed ships, further amplify these risks due to differences in situational awareness and communication protocols. Additionally, existing maritime regulations lack comprehensive guidelines for autonomous operations, leading to legal uncertainties regarding liability and protocols.

Addressing educational gaps is also essential by developing specialized training programs for seafarers to manage intelligent navigation systems and respond effectively to emergencies. These issues require careful study to ensure the safe integration of autonomous ships into maritime operations.

4- Research Aim and Objectives

This research aims to conduct a situational analysis of autonomous ships, focusing on their operational feasibility and the role of technology in ensuring safe shipping operations and navigation.

To achieve the research aim, the study will focus on the following specific objectives:

- I. Identify and analyze challenges and risks associated with autonomous ships
- II. Survey existing maritime regulations and identify gaps
- III. Evaluate the role of technology in ensuring navigation safety

5- Research Methodology

This study combined descriptive and analytical methods to investigate the impact of autonomous ships on navigation safety. Descriptive research focused on surveying autonomous ships and their impact on navigation safety, employing survey techniques such as comparative and correlational methods. Analytical research involved evaluating existing data to critically assess the relationships and patterns observed.

Data were collected from websites, the Arab Academy Maritime Library, scientific books, and a survey of maritime industry experts. The analysis was conducted to identify patterns and relationships within the data. This mixed approach ensured a thorough and systematic understanding of the topic.

6- Research Questions

- I. What are the main challenges and expected problems faced autonomous ships?
- II. What are the risks that impact the safety of navigation for autonomous ships?
- III. What is the impact of autonomous ships on navigation safety?

7- The Concept of Autonomous Ships

Class NK (2021) defines an ‘Autonomous Navigation Ship’ as a vessel that can navigate itself automatically by using sensors to recognize objects in its surroundings, determine collision risks, make decisions without human intervention, take evasive actions, and return to its intended course without requiring control by a human operator.

Autonomy, meaning “self-governing,” covers various levels of independence. IMO defines MASS as vessels capable of operating with varying degrees of human interaction. Central to this model is the shore control center (SCC), which allows operators to monitor and control multiple vessels remotely, thereby cutting operational expenses (Hoem et al., 2019).

7.1 Autonomous Ships Development Projects

Recent advancements in autonomous ship technology are showcased by key projects such as Norway’s MUNIN, which addresses seafarer shortages and promotes sustainable shipping, and DNV GL’s ReVolt, focusing on short-sea autonomous shipping prototypes to enhance safety and reduce logistics strain (Munim, 2019). The YARA Birkeland, the world’s first fully electric autonomous container ship, aims to cut emissions and traffic congestion (Yara, 2019). Other notable developments include Kongsberg Maritime’s autonomous ferry operations, Wärtsilä’s automated navigation systems, and Rolls-Royce’s fully autonomous ferry Falco, which successfully completed sea trials demonstrating safe navigation (Rolls-Royce, 2018). The global autonomous ship market is projected to grow from \$6.88 billion in 2022 to \$9.47 billion by 2027, at a CAGR of 6.6% (Research and Markets, 2023).

The development of autonomous ships has advanced rapidly, while companies like Kongsberg and Rolls-Royce Marine push towards commercializing fully autonomous vessels, regulatory uncertainty remains regarding the application of existing IMO regulations to MASS, highlighting the need for a dedicated framework to govern their interaction with crewed vessels.

8- Level of Autonomy

Autonomy in maritime navigation refers to the shifting balance of decision-making responsibilities between humans and automated systems. This spectrum ranges from full human control to complete system autonomy without human intervention. As autonomy increases, human involvement decreases, with navigation decisions increasingly made by IT-driven algorithms. This shift challenges traditional navigation practices and raises legal concerns, particularly because

current collision avoidance regulations assume human participation and emphasize “good seamanship” (Ringbom, 2019).

8.1 Degrees of Automation for IMO Regulatory Scoping Exercise (RSE)

The IMO defines four degrees of autonomy for MASS to harmonize understanding among stakeholders as follows:

Degree One: A ship equipped with automated processes and decision-support functions, with seafarers onboard to operate and control the systems.

Degree Two: A remotely controlled ship with seafarers onboard; controlled from another location but with crew present to manage systems.

Degree Three: A remotely controlled ship without seafarers onboard; controlled entirely from another location.

Degree Four: A fully autonomous ship capable of making decisions and determining actions independently.

8.2 Factors in the Classification of Automation Levels

Class NK (2021) identifies key factors influencing automation classification:

- Control Modes: Ranging from manual to fully automated control.
- Information Support: Whether automation provides information to humans.
- Human Approval Requirement: Whether human consent is needed before actions.
- Transition of Control: Shift from human to system control.
- Means of Intervention: Availability of human override.
- Reporting to Humans: Whether the system reports actions to maintain oversight.

These factors form a comprehensive framework for understanding automation in maritime systems. These classification frameworks from LR, DNV GL, BV, and Class NK provide essential guidance for defining autonomy levels, balancing human involvement, and ensuring safety.

9- Autonomous Ship Regulatory Frameworks

At the IMO’s 109th Maritime Safety Committee session (MSC 109) in December 2024, progress was reported on developing a goal-based regulatory instrument for MASS. This framework aims to supplement existing conventions like SOLAS by addressing the unique operational characteristics of MASS, including remote control and autonomous functions, while ensuring safety, security, and environmental protection (IMO, 2024).

However, binding regulations and formal definitions for unmanned vessels remain under development, with mandatory adoption of a MASS Code anticipated around 2032, subject to technological and regulatory progress. Until then, unmanned vessels cannot be considered seaworthy under international law, posing significant barriers to their global navigation (IMO, 2024).

10- The Main Challenges Faced Autonomous Ships

While autonomous and remotely controlled ships are envisioned as the future of maritime operations, several challenges have been identified. Encompass legal aspects, safety, risk management, reliability, qualifications and watchkeeping requirements for remote control operators, economic considerations, cybersecurity, and numerous other hurdles. Disruptive technologies offer new capabilities and solutions but also introduce new risk profiles, quality assurance challenges and safety management complexities. Traditionally, responsibility has always been attributed to human agents or organizations, such as a shipping company. It is difficult to assign responsibility for wrongdoing to an algorithm of MASS.

10.1 Regulatory Challenges

Current international maritime regulations including COLREGs, UNCLOS, SOLAS, STCW, and the ISM Code are designed around the assumption that ships are operated by a master and crew, creating legal challenges for autonomous vessels regarding command responsibility and liability (Liu, 2019). Despite technological advances, autonomous ships must comply with safety regulations, necessitating new rules tailored to their unique operations (Kim et al., 2020).

SOLAS Convention sets minimum safety standards for ship construction and operation, enforced by flag states through certification and port state control (SOLAS, 1974). Existing technical regulations were originally designed with the assumption that humans would perform certain functions, which presents challenges when applied to MASS. For example, SOLAS Chapter V Regulation 14 mandates that administrations establish appropriate minimum safe manning for all ships. Regulation 24 requires manual steering in areas of high traffic density, restricted visibility, and other navigationally hazardous situations. Furthermore, Regulation 33 addresses obligations and procedures for dealing with distress situations. These requirements pose difficulties for autonomous ships, and thus, these regulations may need to be adapted to accommodate the new reality of crewless vessels (SOLAS, 1974; Komianos, 2018)

Similarly, STCW Convention, which governs seafarer qualifications, does not address shore-based operators or programmers who control autonomous ships remotely. This gap raises questions about training, certification, and legal responsibility for remote operators, necessitating updates or new conventions (Komianos, 2018; Liu, 2019).

COLREGs, the international “Rules of the Road,” rely heavily on human judgment and lookout duties, complicating their application to autonomous ships. COLREG rules require revision to address autonomous ships, including Rule 2 on responsibility, emphasizing the need for experienced operators; Rule 3’s vessel definition, which currently excludes autonomous ships; Rule 5 on lookout, highlighting the controversy over replacing human senses with technology and Rules 6, 7, and 8 stress safe speed, risk of collision and seamanship, underscoring the importance of human expertise or its equivalent in remote control centers. Rule 19’s reliance on auditory signals and Rule 20’s emphasis on navigational lights further illustrates the need for amendments

to accommodate autonomous vessels and ensure maritime safety (COLREG, 1972; Komianos, 2018; Liu, 2019).

Under UNCLOS Article 94, vessels must be commanded by qualified masters, raising legal questions about whether Ship Control Centres can fulfill this role for autonomous ships (UNCLOS, 1982). Coastal states must allow innocent passage of autonomous vessels but may impose pilotage or port restrictions, affecting their operational freedom (Leopardi, 2022; Brill, 2022).

SAR Convention, focused on manned ships, assigns rescue duties to the ship's master, posing challenges for autonomous vessels lacking onboard personnel. Amendments are likely needed to address these operational gaps. Insurance issues also arise, as minimum safe manning requirements may render autonomous ships unseaworthy under current marine insurance laws, potentially affecting coverage. Finally, the ISM Code requires safety management systems and trained personnel onboard. To accommodate autonomous vessels, amendments are proposed to assign equivalent responsibilities to shore-based masters and remote operators (Komianos, 2018).

10.2 Operational Challenges

All vessels, manned or unmanned, must comply with international regulation, which assume onboard personnel to ensure compliance. Autonomous ships face challenges in congested waters where effective verbal communication with manned vessels is essential for safe maneuvering (Liu, 2019). While largely experimental, autonomous vessels must address system reliability, as minor failures without crew intervention could escalate. Lessons from unmanned spacecraft reliability engineering offer promising approaches to enhance safety (Felski and Zwolak, 2020).

Remotely operated ships suffer from limited situational awareness due to lack of direct visual confirmation, and fully autonomous vessels raise concerns about AI's ability to consistently make safe decisions in dynamic conditions like weather changes and complex maneuvers such as berthing (Liu, 2019). The Advanced Autonomous Waterborne Applications (AAWA) project proposes combining radar, cameras, AIS, and sound sensors to approximate human situational awareness, though effective communication remains a challenge (Kooij et al., 2018).

Route planning is a critical function for autonomous ships, involving the selection of the safest and most efficient paths while considering weather, legal requirements, and fuel efficiency (Yanchin and Petrov, 2020). Unlike crewed vessels where navigators manually adjust routes, autonomous ships rely on onboard systems or shore control centers to manage this complex task. Integration of weather data helps optimize sailing time and reduce fuel consumption. Algorithms are commonly used for constrained pathfinding, while AI techniques like Machine Learning and Deep Learning show promise in enhancing route optimization. However, the application of Reinforcement Learning remains limited due to the challenges of operating in diverse and accident-prone maritime environments. Overall, advanced algorithms combined with real-time data are essential to improve safety and efficiency in autonomous ship navigation.

Ensuring route correctness involves evaluating characteristic coefficients to detect deviations that may increase accident risk. Autonomous ships must also coordinate actions with nearby vessels, using distributed consensus algorithms when only autonomous ships are present, or specialized communication units to interact with manned ships, ensuring safe navigation (Yanchin and Petrov, 2020).

Remote monitoring relies on extensive sensor networks transmitting data to shore-based centers, requiring robust data science capabilities for predictive maintenance and performance optimization. To maintain operational robustness, distributed software architectures like actor models are employed, enabling fault tolerance and graceful recovery from failures (Yanchin and Petrov, 2020). Communication remains a critical challenge. Ship-to-ship communication, especially between autonomous and manned vessels, is complex and underexplored, while ship-to-shore communication faces high costs and bandwidth limitations, impeding real-time control during critical situations (Kooij et al., 2018; Felski and Zwolak, 2020). Addressing these communication barriers is vital for the safe and effective deployment of autonomous shipping.

Maintenance and repair present significant challenges for autonomous ships due to the absence of onboard crews, necessitating reliance on advanced technologies and remote monitoring to ensure operational reliability. Condition-Based Maintenance (CBM) is a promising strategy that utilizes real-time sensor data such as vibration, temperature, and fuel efficiency to assess equipment health and predict failures, enabling maintenance based on actual conditions rather than fixed schedules (Breaking Defense, 2022). The NYK Group has integrated AI with CBM to enhance failure prediction and facilitate proactive interventions by sharing data with classification societies and manufacturers (Bindt, 2020). However, CBM primarily supports scheduled maintenance during port stays, highlighting the need for autonomous repair solutions.

Port operations will also be affected, as automation transfers some vessel tasks to shore-based control, requiring ports to upgrade skills, equipment, and governance models to ensure compatibility with autonomous systems (Ghaderi, 2019).

10.3 Safety Challenges

MASS introduce new safety challenges despite reducing human-related risks. Increased autonomy raises concerns about collision avoidance, cyberattacks, system failures, and operational malfunctions, especially in congested waters where interpreting COLREGs and effective communication between manned and unmanned vessels are critical (Liu, 2019; Kim et al., 2022). Autonomous systems must accurately perceive, predict, and respond to dynamic environments, yet limitations in AI decision-making and sensor reliability pose risks, particularly during complex maneuvers like berthing (Liu, 2019).

Ensuring seaworthiness relies on advanced onboard control systems utilizing sensors, machine learning, and deep neural networks to monitor vessel conditions and adapt to changing environments (Yanchin and Petrov, 2020). Collision avoidance depends on reliable sensor data and sophisticated algorithms, but unpredictability in human-operated vessels interacting with

autonomous ships complicates safe navigation. Operator training is essential to manage automated systems effectively and mitigate risks associated with loss of situational awareness (Felski and Zwolak, 2020).

The integration of unmanned and autonomous vessels into existing maritime traffic presents complex challenges, particularly in collision avoidance. As highlighted, the degree of human intervention, sensor reliability, and operator training are critical factors influencing safety. The unpredictability of human-operated vessels interacting with autonomous ships underscores the need for robust algorithms and improved communication protocols. Notably, developments such as real-time multi-sensor systems and AI-driven decision-making show promise but remain limited in scope. The recent IMO MSC 109/5 emphasizes adapting regulations and technologies like AIS enhancements to facilitate safer coexistence between manned and unmanned vessels, marking a crucial step toward harmonized maritime operations.

10.4 Security Challenges

Autonomous ships face significant security challenges due to the absence of crew and heavy reliance on automation and connectivity. The introduction of the ISPS Code under SOLAS Chapter XI-2 post-9/11 highlights the importance of maritime security, autonomous vessels remain vulnerable to piracy, hijacking, terrorism, and misuse, particularly when transporting hazardous materials (Komianos, 2018; Liu, 2019). Cybersecurity risks are heightened as these ships depend on complex software and communication links, making them susceptible to hacking, malware, GPS spoofing, ransomware, and unauthorized access to critical systems (Issa et al., 2022).

The integration of cyber-physical systems across perceptual, network, support, and application layers expose autonomous ships to remote electronic interference without physical breaches (Issa et al., 2022). Potential cyberattacks can disrupt navigation, cause environmental damage, compromise sensitive data, and facilitate illicit activities such as smuggling or vessel hijacking. Consequently, robust cybersecurity frameworks, including encryption, contingency planning, and updated inspection protocols, are essential to mitigate these threats (Kim et al., 2020; IMO, 2024).

In summary, while autonomous shipping offers operational and sustainability benefits, significant regulatory, legal, and operational challenges remain. The IMO MSC 109/5 code emphasizes the urgent need for enhanced risk management and port security measures to safeguard autonomous vessels. Addressing these security challenges is critical to ensuring the safe, resilient, and secure operation of MASS in the evolving maritime landscape. Updating and harmonizing international conventions is essential to safely integrate autonomous vessels into global maritime operations.

11- Risks of Autonomous Ships on Navigation Safety

Autonomous ships have the potential to transform maritime transport by improving efficiency and reducing human error, but they also pose significant navigation safety risks. Their reliance on sensor systems and AI algorithms integrating RADAR, LIDAR, cameras, and AIS data for obstacle detection and navigation makes them vulnerable to sensor failures, adverse weather, and cyberattacks, which can compromise situational awareness and increase collision risks (Virtue Marine, 2025; Fraunhofer CML, 2015). Additionally, dependence on technologies like GNSS and

fleet management software raises concerns, as system and equipment failures caused 25.9% of maritime incidents from 2014 to 2023. The lack of onboard crews to manage malfunctions in real time further heightens these dangers (EMSA, 2024). While autonomous shipping reduces human error, it introduces new risks related to system reliability and sensor accuracy, with failures in automation algorithms or sensor fusion potentially causing catastrophic outcomes if not properly managed (Warontherocks, 2022).

To mitigate these risks, autonomous ships must implement redundancy, advanced self-diagnostics, and predictive maintenance systems that monitor health and provide early failure warnings. Furthermore, comprehensive training for remote operators is critical to manage emergencies effectively and ensure safe navigation (Virtue Marine, 2025).

The absence of an onboard ship master in unmanned vessels, with control shifted to Shore Control Centers (SCCs), raises significant legal and regulatory issues. Liability traditionally shared among the master, owner, and classification society becomes complex, as remote operators assume the master's responsibilities. Liability may extend to SCC personnel or management, especially when multiple vessels are controlled simultaneously, and manufacturers may also be liable for system defects (Kennedys Law, 2018; Burns & Wilcox, 2019).

Cybersecurity threats represent a critical vulnerability. Autonomous ships are highly reliant on interconnected digital systems, making them susceptible to hacking, GPS spoofing, and signal jamming. Such attacks could manipulate navigation data or disable control systems, potentially leading to accidents or vessel hijacking (War on the Rocks, 2023; CCDCOE, 2024). The absence of onboard crews exacerbates these risks, as immediate human intervention is unavailable to counteract system failures or security breaches. Evidence in legal proceedings will rely heavily on electronic sensor data and logs rather than crew testimonies, raising concerns about data integrity and admissibility. Robust cybersecurity and standardized data protocols are essential (MUNIN, 2015; SMASH Roadmap, 2022).

Furthermore, autonomous systems may struggle to handle complex, dynamic maritime environments such as congested ports or restricted waters where unpredictable human behaviors prevail. The limited ability to adapt to unforeseen scenarios without human intuition raises concerns about operational safety (DNV, 2025). Although automation facilitates proactive emergency management and real-time monitoring, it also introduces challenges. The vast amount of sensor data can lead to information overload during critical situations, potentially hindering effective decision-making. Moreover, ensuring the reliability of sensor fusion technologies is essential, as sensor faults or interface issues may exacerbate emergencies if not properly addressed (Jalonen et al., 2017).

The management of emergencies on autonomous ships is a critical area of research as these vessels rely heavily on advanced systems to handle failures without human intervention. Effective

handling of failure modes such as impaired thrusters, total blackouts, and extreme weather conditions is essential to ensure operational safety and reliability.

In conclusion, while autonomous ships offer significant benefits, their impact on navigation safety involves technological, cybersecurity, regulatory, and operational risks. Addressing these challenges through robust sensor technologies, cybersecurity protocols, updated regulations, and human oversight integration is essential to ensure safe maritime navigation.

12- Flag States view on autonomous ships

Flag States face complex legal, regulatory, and operational risks regarding MASS due to the absence of a comprehensive international framework, with mandatory IMO regulations expected only by 2032 (GAO, 2024; UNCTAD, 2022). Many flag States, especially developing countries, lack adequate port infrastructure for remote monitoring, cybersecurity, and emergency response (UNCTAD, 2022). Cybersecurity vulnerabilities and increased physical security risks, including piracy, pose further challenges (GAO, 2024). Jurisdictional issues arise from delocalized control via Shore Control Centers, complicating enforcement. Social concerns about workforce displacement also affect acceptance (UNCTAD, 2022). A coordinated international approach is vital for safe MASS integration.

13- Effects of Autonomous Ships on Navigational Safety

The data reveals a cautious approach towards autonomous technology, with a majority expressing skepticism about the safety and reliability of autonomous vessels compared to traditional crewed ships. Concerns about system failures, cybersecurity threats, and navigational capabilities in complex environments dominate respondents' perceptions. For instance, a notable 61.2% of participants express significant concern regarding cybersecurity vulnerabilities, while 50% are somewhat concerned about system failures affecting navigation safety. These apprehensions underscore the urgent need for robust cybersecurity measures and reliable system designs to enhance trust in autonomous operations.

Moreover, the findings highlight a critical demand for human oversight in various operational scenarios. A substantial majority believes that human operators should remain involved in decision-making processes, particularly in high-risk situations or emergencies. This sentiment is echoed by the perception that autonomous ships require human intervention for effective navigation and hazard management. Such views indicate that while technological advancements are recognized, there remains a strong belief in the necessity of human expertise to mitigate risks associated with automation.

Additionally, the survey results suggest that regulatory frameworks currently inadequately address the unique challenges posed by autonomous vessels. A significant 59.5% of respondents feel that existing regulations only partially cover safety concerns related to autonomous navigation, emphasizing the need for tailored legal frameworks to ensure operational safety and accountability.

14- Conclusion

while autonomous ships hold great potential for improving navigation safety through technological innovation, significant challenges remain. Addressing these concerns requires advancements in AI reliability, cybersecurity measures, and regulatory clarity. A hybrid approach combining automation with human oversight appears to be the most viable path forward for ensuring safe integration into global maritime operations. Through continued research and collaboration between industry stakeholders and regulatory bodies, autonomous ships can achieve their potential as a safer alternative to conventional navigation systems.

15- Recommendations

To ensure the safe integration of autonomous ships into maritime navigation, several key recommendations are essential.

- Enhancing sensor reliability through the integration of radar, lidar, and cameras is critical to provide comprehensive situational awareness, supported by continuous testing in diverse conditions.
- Advanced collision avoidance systems must be developed that comply with COLREGs and adapt to dynamic maritime environments, improving decision-making during interactions with manned vessels.
- Robust cybersecurity measures including secure communications, intrusion detection, and regular software updates are vital to protect autonomous ships from cyber threats and build trust in their operation.
- Clear regulatory frameworks tailored to autonomous shipping should be established, addressing safety standards, liability, and inspection protocols, with collaboration between the IMO and industry stakeholders.
- Promoting human oversight through comprehensive training programs ensures operators can effectively manage autonomous systems and respond to emergencies, complementing technological advances with human expertise.

Implementing these recommendations will help the maritime industry safely embrace autonomous shipping while mitigating associated risks.

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