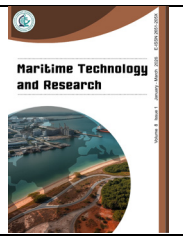
Maritime Technology and Research

https://so04.tci-thaijo.org/index.php/MTR



Research Article

Operating autonomous tanker vessels in Malaysian territorial waters: Focus on security and emergency response preparedness

Rasyidah Mohd Sani and Mohammed Ismail Russtam Suhrab*

Faculty of Maritime Studies, University Malaysia Terengganu, Kuala Terengganu 21030, Malaysia

Corresponding author's e-mail address: m.ismail@umt.edu.my

Article information

Received: January 22, 2025
Revision: April 24, 2025
Accepted: September 9, 2025

Keywords
Autonomous vessels; cybersecurity; emergency response, maritime infrastructure, Malaysian territorial waters

Abstract

This research investigates Malaysia's preparedness for deploying autonomous tanker vessels within its territorial waters, with an emphasis on cybersecurity and emergency response strategies. The study fills a critical research gap by analyzing the perspectives of 100 maritime stakeholders, including shipowners, port authorities, regulatory bodies, and cybersecurity experts, to assess the technological, infrastructural, and policy challenges Malaysia faces in adopting autonomous shipping. The methodology integrates qualitative interviews and surveys to explore concerns such as cybersecurity risks, emergency response mechanisms, and port infrastructure readiness. Key findings reveal moderate awareness of autonomous technologies, with significant concerns about cybersecurity vulnerabilities, the absence of adequate regulatory frameworks, and infrastructural deficiencies. Public acceptance of these technologies remains a challenge, highlighting the need for better stakeholder engagement. Recommendations focus on enhancing cybersecurity protocols, developing comprehensive emergency response systems, and fostering regional collaboration to support a smooth transition to autonomous maritime operations in Malaysia.

1. Introduction

The global maritime industry is undergoing a significant transformation with the advent of autonomous technologies. Driven by advancements in artificial intelligence, automation, and sensor technologies, autonomous vessels have the potential to revolutionize maritime operations by improving operational efficiency, reducing human error, and enhancing safety (Zhou et al., 2022). With over 80 % of global trade relying on maritime transport (UNCTAD, 2018), the maritime sector plays a crucial role in international commerce, making the integration of autonomous vessels a topic of immense significance. While countries such as Norway, Finland, Japan, and Singapore have made considerable advancements in autonomous shipping, Malaysia faces unique challenges in adopting these technologies, particularly within the context of autonomous tanker vessels (Haas & Liss, 2020). Malaysia's position in the Straits of Malacca, one of the busiest and most strategically important waterways in the world, underscores its pivotal role in regional and global maritime trade. The Straits serve as a critical chokepoint for over a quarter of the world's oil trade and a significant percentage of global container traffic, making it an essential area for considering the transition to autonomous vessels.

However, the integration of autonomous vessels in the Straits of Malacca is not without challenges. The region's heavy traffic, complex navigation environment, and geopolitical

considerations pose unique obstacles for deploying autonomous ships. Furthermore, the vulnerability to criminal activities such as piracy and hijacking remains a significant concern. Notably, incidents such as the hijacking of the MT Orkim Harmony in 2015, which involved the theft of fuel cargo, and the MV Wakashio oil spill in 2020, which caused an environmental disaster, highlight the security vulnerabilities within Malaysia's maritime sector. These incidents emphasize the urgent need for enhanced security measures, better surveillance, and more robust emergency response systems, which are critical as Malaysia moves toward adopting autonomous vessels.

The need for a comprehensive security framework is also critical, especially when considering the risks associated with autonomous operations, such as cyberattacks, unauthorized access, and potential system failures that could lead to catastrophic consequences. The lack of specialized infrastructure, regulatory frameworks, and cybersecurity protocols further compounds these issues, making Malaysia's preparedness for autonomous vessel adoption an urgent matter. This study focuses on assessing Malaysia's readiness to adopt autonomous tanker vessels within its territorial waters. By examining the perspectives of 100 maritime stakeholders, including shipowners, regulatory agencies, port authorities, and cybersecurity experts, the study investigates barriers such as cybersecurity threats, inadequate regulatory frameworks, and the need for improved port infrastructure. To frame this transition, the study also references the International Maritime Organization's (IMO) definition of autonomy, which categorizes ships based on their level of automation (IMO, 2018). This framework will help evaluate Malaysia's preparedness to accommodate various levels of autonomous operations, particularly in a busy maritime environment like the Straits of Malacca. This study, therefore, assesses Malaysia's readiness to adopt autonomous tanker vessels by identifying gaps in security protocols, infrastructure preparedness, and emergency response mechanisms. Addressing these gaps is essential for a smooth transition to autonomous maritime operations in Malaysia.

To guide this investigation, the following research questions are posed:

- What are the main challenges Malaysia faces in utilizing advanced technologies and automation to improve the security and emergency response for autonomous tankers in its waters?
- How can automation and advanced technology improve safety, efficiency, and security for autonomous tankers operating in Malaysia's territorial waters?
- What strategies are used to boost emergency response and protect both maritime assets and the environment in Malaysia's waters?

Based on these questions, the study aims to:

- Examine the challenges of using advanced technology and automation in Malaysia's maritime security and emergency response for autonomous tankers.
- Assess how automation improves safety, efficiency, and security for autonomous tankers in Malaysia's waters.
- Suggest strategies to improve emergency response and protect both maritime assets and the environment in Malaysia's waters

2. Literature review

The maritime industry is undergoing a transformative phase, driven by the advent of autonomous shipping technologies. These innovations, powered by advancements in artificial intelligence, automation, and real-time data integration, have the potential to revolutionize maritime operations globally. Autonomous ships promise enhanced efficiency, reduced operational costs, and improved safety, making them pivotal in modern logistics and transportation systems (Zhou et al., 2022). Additionally, these technologies align with global efforts to reduce carbon emissions, contributing to environmental sustainability through optimized fuel consumption and zero-emission electric ships.

Globally, countries such as Norway, Japan, and Finland have emerged as leaders in the development of autonomous shipping. Notable initiatives, including the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project, YARA Birkeland, and the Advanced

Autonomous Waterborne Applications Initiative (AAWA), demonstrate how strategic investment and research can drive the successful implementation of autonomous technologies. These projects focus on improving operational efficiency, reducing human error, and addressing legal, regulatory, and technological challenges (Ben et al., 2022; Bielawski & Lazarowska, 2022). For instance, YARA Birkeland represents the world's first zero-emission, fully autonomous container ship, while the AAWA initiative explores the social and economic implications of adopting autonomous vessels. **Table 1** provides an overview of major autonomous shipping projects globally, highlighting their objectives and the region leading these advancements.

Table 1 Major projects in autonomous shipping.

Project	Year	Objectives	Team Location
MUNIN - Maritime Unmanned Navigation through Intelligence in Networks	2012	Develop and verify concepts for autonomous shipping.	Norway, Germany
ReVolt	2013	Move more transport from land to sea; facilitate short sea shipping and build more maritime infrastructure.	Norway
SSAP - Smart Ship Application Project	2015	Utilize the smart ship concept to achieve optimal ship operation, safety, and energy efficiency.	Japan
AAWA - Advanced Autonomous Waterborne Applications Initiative	2016	Produce designs and explore the social and economic implications of autonomy.	Finland
YARA Birkeland	2017	Create zero-emission, electric autonomous ships.	Norway
D4V - Design for Value	2017	Enable the best use of digital disruption for business growth through a door-to-door supply chain with a fully autonomous system-of-systems.	Finland
NOVIMAR	2017 - 2021	Optimize waterborne transportation for full use of short sea, sea-river, and inland waterways.	Netherlands
Zhi Fei	2020/2021	Undertake short-sea operations	China
Rolls-Royce -Autonomous Ships	2020-Present	Develop autonomous ships with AI decision-making.	United Kingdom, Finland, Singapore
China Merchants Energy Shipping	2020	Test autonomous tankers for energy transport.	China
Sea Machines Robotics	2021-Present	Develop autonomous piloting systems for safer and efficient vessels.	United States, United Kingdom
Kongsberg Gruppen - Remote Controlled Ships	2021-Present	Integrate remote control and autonomy for safer shipping.	Norway, United States
Deep Green	2021-Present	Expand autonomous technology for underwater exploration.	United Kingdom, International
OCEAN-AV	2022	Use AI to create safer and more efficient maritime environments.	United States, Canada
Eco Ship Fleet	2022	Launch an eco-friendly autonomous shipping fleet.	Japan, International
Maritime Robotics - SeaShuttle	2023-Present	Develop autonomous shuttles for offshore industries.	Norway, Denmark

Source: Compiled from various sources (2024).

Malaysia, strategically positioned along the Straits of Malacca, stands to benefit significantly from autonomous shipping technologies. As one of the busiest and most critical maritime trade routes globally, the Straits of Malacca underscores Malaysia's importance in global shipping networks. The adoption of autonomous shipping could enhance Malaysia's competitiveness, improve operational efficiency, and contribute to environmental goals. The economic and environmental benefits of autonomous shipping further emphasize its transformative potential. By minimizing human error, autonomous vessels improve operational safety and reduce accidents in congested waterways. However, cybersecurity represents a significant concern for autonomous vessels. These ships rely heavily on interconnected digital systems, making them susceptible to threats such as hacking, data breaches, and spoofing. Ben et al. (2020) emphasize the critical need for robust cybersecurity measures to mitigate these risks. Investments in advanced technologies and comprehensive stakeholder training programs are essential to safeguard autonomous tanker operations and ensure secure navigation through congested waterways such as the Straits of Malacca (Bielawski & Lazarowska, 2022). Emergency preparedness is another area requiring significant attention. The complexity and density of traffic in the Straits of Malacca necessitate robust emergency response frameworks to address potential incidents involving autonomous vessels. Montewka (2019) highlights the importance of real-time monitoring, automated emergency systems, and coordinated regional efforts to enhance maritime safety.

The shift to zero-emission electric ships contributes to reducing carbon footprints, aligning with international sustainability goals. Despite these benefits, the integration of autonomous shipping in Malaysia is constrained by gaps in regulatory frameworks, public awareness, and technological infrastructure (Haas & Liss, 2020; Rahman, 2022). Addressing these barriers will require targeted investments, comprehensive policy reforms, and strong stakeholder engagement.

3. Research methodology

3.1 Data collection

Data collection in this study was conducted through structured surveys and interviews involving a total of 105 maritime industry stakeholders. This included a pilot study with 5 participants from different maritime sectors to test the clarity and reliability of the survey instrument. After the pilot, data from 100 valid respondents were used for the main analysis. These respondents included 30 port operators, 40 representatives from shipping companies, 20 officials from maritime regulatory authorities, and 10 maritime educators. While the study did not include direct representatives from specialized maritime security agencies, the perspectives of port operators and regulatory authorities captured key insights related to maritime safety and emergency preparedness. Educators were included due to their academic expertise in maritime technology, international maritime law, and future policy development areas critical to understanding Malaysia's readiness for autonomous tanker vessel operations.

The survey instrument focused on three key areas: General Knowledge and Perception, Security Protocols, and Emergency Protocols. The first section gauged respondents' awareness and understanding of autonomous vessels. The second assessed existing security measures, including those addressing cyber threats and piracy. The final section examined emergency preparedness, focusing on protocols for accidents, system failures, and natural disasters. The full questionnaire is included in **Appendix A**.

The data collection focused on three main sections: General Knowledge and Perception, Security Protocol, and Emergency Protocol. The General Knowledge and Perception section gathered information about respondents' understanding, awareness, and perceptions of autonomous tanker vessels in Malaysian territorial waters. The Security Protocol section focused on measures implemented to protect autonomous vessels from unauthorized access, cyber threats, piracy, and other

security breaches. The Emergency Protocol section examined plans and procedures for handling accidents, malfunctions, and natural disasters related to autonomous vessels.

3.2 Data analysis

The collected data was analyzed using a mixed-method approach that combined quantitative and qualitative techniques. Quantitative analysis was conducted using SPSS software, focusing on descriptive statistics such as frequencies and percentages to summarize stakeholder perceptions of technological readiness, security protocols, and emergency response preparedness. Qualitative analysis involved thematic evaluation of open-ended responses and interview data. This approach helped uncover recurring themes, challenges, and best practices across the different stakeholder groups, adding depth and context to the overall findings.

3.3 Data interpretation

The interpretation of the data was aligned with the research objectives. The findings were used to identify challenges, evaluate the current state of preparedness, and suggest opportunities for Malaysia to enhance its capabilities in adopting autonomous tanker vessels. Recommendations were made to improve security, emergency response frameworks, and stakeholder engagement.

4. Results and discussion

4.1 Results overview

This study analyses data collected from 100 valid respondents in the maritime industry. These participants were selected following a pilot study involving 5 initial testers, whose responses were excluded from the final analysis. The 100 respondents include professionals from shipping companies, port authorities, regulatory agencies, and maritime educators, ensuring diverse and relevant perspectives.

The data collection utilized structured surveys and interviews focusing on general knowledge, security protocols, and emergency protocols regarding autonomous tanker vessels in Malaysia's territorial waters.

4.2 Result of analysis: General knowledge and perception

The results reveal several critical findings. The familiarity with autonomous vessel technology was notably low (mean = 2.08), indicating a general lack of awareness among industry stakeholders. This is consistent with findings from Bielawski and Lazarowska (2022), who highlighted gaps in knowledge regarding autonomous technologies in Southeast Asia's maritime industry. Moreover, the awareness of initiatives scored the lowest (mean = 1.61), pointing to an urgent need for better communication and public outreach efforts to build awareness and trust in autonomous vessels (**Table 2**).

Although these benefits are widely recognized in the literature, respondents in this study confirmed their relevance, particularly citing enhanced efficiency and reduced human error, with a mean score of 2.51. These perceptions align with previous studies, such as Deloitte (2020), which identified such factors as foundational motivations for developing autonomous shipping. However, the more critical insight from this study is the higher concern over cybersecurity risks, infrastructure readiness, and regulatory gaps, reflected by a higher mean score of 2.98, supporting the challenges highlighted by Hosseini and Karimi (2021).

Technological readiness scored relatively high (mean = 3.22), suggesting a moderate level of confidence in Malaysia's current technological infrastructure to support autonomous operations. Nevertheless, infrastructure readiness (mean = 2.69) highlighted the need for significant

improvements in communication networks and navigation systems to accommodate the deployment of autonomous vessels.

Table 2 Statistics of General Knowledge and Perception.

	Mean	Std. Error of Mean	Std. Deviation	Sum
Familiarity with autonomous vessel technology	2.0800	0.05976	0.59764	208.00
Potential benefits of autonomous tanker vessels	2.5100	0.13295	1.32950	251.00
Main challenges or concerns	2.9800	0.13705	1.37054	298.00
Technological readiness	3.2200	0.10404	1.04040	322.00
Infrastructure requirements	2.6900	0.11520	0.11520	269.00
Awareness of initiatives	1.6100	0.04902	0.49021	161.00
Potential economic impacts	2.3900	0.10531	1.05309	239.00
Public acceptance and trust	2.3000	0.07850	0.78496	230.00
Factors influencing public perception	2.3900	0.10815	1.08148	239.00

Source: Authors.

4.3 Result of analysis: Security protocol

The results show that current security measures for conventional tanker vessels in Malaysia's territorial waters received a moderately high score (mean = 3.09), indicating some confidence in existing measures. However, the importance of establishing specific security protocols for autonomous vessels scored the lowest (mean = 1.43), revealing a significant gap in prioritizing the security needs of autonomous shipping.

Cybersecurity preparedness scored moderately (mean = 2.70), indicating a basic level of awareness among stakeholders. However, this should not be interpreted as evidence of structured readiness specific to autonomous tanker vessels. In fact, low awareness of applicable cybersecurity regulations (mean = 1.68) and protective measures (mean = 1.67) suggests that Malaysia currently lacks a specialized cybersecurity framework tailored for autonomous maritime operations. As Hosseini and Karimi (2021) noted, the absence of clear regulatory and technical preparedness in cybersecurity remains a significant vulnerability. At the time of this study, no national initiatives or protocols specifically addressing cybersecurity for autonomous vessels had been publicly documented (**Table 3**).

4.4 Result of analysis: Emergency protocol

The analysis of emergency protocols for autonomous tanker vessels highlights key insights into preparedness, awareness, and challenges. Existing security measures for conventional vessels scored moderately high (mean 3.09), reflecting some confidence in their effectiveness. However, the importance of establishing specific security protocols for autonomous operations scored the lowest (mean 1.43), demonstrating a critical gap in awareness and prioritization. Awareness of cybersecurity regulations specific to autonomous vessels and familiarity with tailored cybersecurity measures both scored low (mean 1.68 and 1.67, respectively). These findings align with the overall low preparedness levels for cybersecurity threats, although the general confidence in cybersecurity preparedness was moderately higher at 2.70. The findings align with Montewka (2019), who stressed that advanced emergency response systems are crucial for managing the risks associated with autonomous operations. Malaysia's existing infrastructure must be upgraded to integrate automated, real-time response mechanisms to ensure safety in emergency situations (**Table 4**).

Table 3 Statistics of Security Protocol.

	Mean	Std. Error of Mean	Std. Deviation	Sum
Current level of security measures in Malaysia's territorial waters for conventional tanker vessels	3.0900	0.91112	0.91115	309.00
Importance of establishing robust security protocols for autonomous tanker vessels	1.4300	0.07283	0.72829	143.00
Main security challenges for autonomous tanker vessels in Malaysia's territorial waters	2.4700	0.11845	1.18454	247.00
Awareness of specific security regulations for autonomous vessel operations	1.6800	0.04688	0.46883	168.00
Cybersecurity preparedness in Malaysia's territorial waters and maritime operations	2.7000	0.09796	0.97959	270.00
Awareness of specific cybersecurity measures for autonomous vessel operations	1.6700	0.04726	0.47258	167.00
Effectiveness of current cybersecurity measures	2.7700	0.09195	0.91954	277.00

Source: Authors.

Table 4 Statistics of Emergency Protocol.

	Mean	Std. Error of Mean	Std. Deviation	Sum
Criticality of establishing comprehensive emergency protocols for autonomous tanker vessels	4.1300	0.10215	1.02154	413.00
Confidence in current emergency response capabilities	1.8100	0.59789	0.59789	181.00
Key aspects in emergency response protocols	2.7500	0.59789	0.59789	275.00
Rating of existing emergency response capabilities and protocols	2.7900	0.11037	1.10367	279.00

Source: Authors.

4.5 Additional concerns and suggestions regarding emergency protocols

Respondents raised several critical concerns and provided valuable suggestions to enhance emergency protocols for autonomous tanker vessels in Malaysia's territorial waters. Key recommendations included implementing redundancy and fail-safe mechanisms to mitigate risks and ensure safe operations during system failures. Participants emphasized the need to establish standardized procedures and foster international discussions to align Malaysia's frameworks with global maritime safety standards. Comprehensive training for crew, shore personnel, and stakeholders was also highlighted as essential for improving operational efficiency and emergency response. Regional collaboration, particularly among neighboring countries in Southeast Asia, was deemed crucial for managing autonomous vessel operations in busy waterways like the Straits of Malacca.

Respondents expressed concerns about weak cyber infrastructure and insufficient security measures, calling for improved safeguards to protect vessels from potential threats. The importance of gaining support from major oil companies and enhancing marine engineering education to prepare professionals for the unique challenges of autonomous operations was also stressed.

4.6 Analysis of primary benefits of autonomous tanker vessels

The analysis highlights the transformative potential of autonomous tanker vessels for Malaysia's maritime industry and reflects the study's objective of assessing how automation can improve safety, efficiency, and security. Respondents identified several key benefits, including enhanced operational efficiency, reduced human error, and cost savings. These benefits are consistent with findings from Deloitte (2020) and Montewka (2019), which reported that autonomous shipping significantly improves efficiency and safety, as well as reduces operational risks. Furthermore, the integration of advanced automation technologies may support environmental goals through reduced fuel consumption and lower emissions, which is an important consideration as Malaysia aligns with international sustainability commitments.

4.7 Discussion

The findings from this study point to several pressing challenges in Malaysia's readiness to adopt autonomous tanker vessels, especially in the areas of cybersecurity, emergency response, and public trust. Many participants expressed limited awareness of cybersecurity measures specifically designed for autonomous vessels (mean = 1.67). This reflects a wider issue: Malaysia currently lacks detailed regulations and technical frameworks to address the unique cybersecurity demands of unmanned shipping. This aligns with observations by Bielawski and Lazarowska (2022), who highlighted a general absence of tailored cybersecurity policies in Southeast Asia's maritime sector. While Malaysia has implemented broader national strategies, such as the Malaysia Cyber Security Strategy 2020&2024, these initiatives have not yet been extended to specifically cover autonomous maritime systems. Without dedicated protocols, autonomous vessels remain vulnerable to issues like cyberattacks, unauthorized control, or system interference. By contrast, projects like Norway's YARA Birkeland provide a compelling example of how environmental sustainability and secure automation can coexist through integrated planning (DNV, 2021). Malaysia could learn from such models as it considers its own roadmap.

The data also shows that, although participants reported moderate confidence in Malaysia's technological readiness (mean = 3.22), they gave significantly lower scores when evaluating current emergency response capabilities (mean = 1.81). This reinforces Montewka's (2019) argument that conventional emergency systems are inadequate for dealing with incidents involving autonomous or semi-autonomous vessels. Malaysia's heavy reliance on manual alert systems and non-automated emergency procedures suggests the country is not fully equipped to manage high-risk scenarios at sea. This gap is particularly concerning given Malaysia's location along the heavily trafficked Straits of Malacca, which remains a hotspot for piracy and maritime incidents. The International Maritime Bureau (IMB, 2023) continues to rank Southeast Asia among the most at-risk areas globally. Without real-time monitoring and autonomous emergency interventions, Malaysia may struggle to ensure the safety and reliability of its maritime operations.

Equally important is the issue of public and industry acceptance. Trust in autonomous maritime technologies received relatively low scores (mean = 2.30). This echoes global research such as Perera et al. (2020), which emphasizes the importance of public trust and transparency in facilitating technology adoption. In Malaysia, the lack of public education campaigns and stakeholder engagement may be contributing to a cautious or skeptical outlook. Moving forward, Malaysia could benefit from initiatives that demonstrate the safety and value of autonomous shipping, such as pilot programs, training courses, or public exhibitions.

Countries such as Singapore and Norway offer valuable benchmarks for Malaysia's future roadmap. Singapore has integrated digital twin technology and autonomous port operations into its maritime strategy, while Norway's YARA Birkeland is a global example of zero-emission, fully autonomous shipping backed by strict cybersecurity protocols. In contrast, Malaysia's preparedness remains limited, particularly in dedicated cybersecurity regulations and autonomous emergency response systems. By establishing simulation testbeds and port-based digital command centers similar to Norway's and Singapore's models, Malaysia can close key infrastructure and governance gaps.

Lastly, the study suggests that regional collaboration could significantly improve Malaysia's readiness. By working with neighbors like Singapore, which is already advanced in maritime digitization, Malaysia could accelerate its development through shared protocols, data exchanges, and coordinated emergency response strategies. Ongoing efforts like the MIMA and MPA Singapore Dialogues (2022) offer a promising platform for such cooperation. In summary, while there is some groundwork in place, Malaysia still has much to do before it can confidently adopt autonomous tanker vessels. Addressing gaps in cybersecurity, emergency response, and public trust will be critical steps in this journey.

5. Recommendations

Based on the findings of this study, several key recommendations are proposed to help Malaysia prepare for the integration of autonomous tanker vessels. These focus on strengthening cybersecurity, improving emergency response systems, and promoting regional cooperation. First, Malaysia needs to develop a cybersecurity framework specifically for autonomous shipping. This includes adopting advanced encryption, conducting regular security assessments, and providing training for stakeholders such as crew members, regulators, and maritime authorities. Malaysia should also align its cybersecurity measures with international standards, like those from the International Maritime Organization (IMO), to stay up to date with global best practices.

Next, Malaysia should improve its emergency response capabilities by investing in real-time monitoring systems and automated response mechanisms. This will help ensure quick and effective action in the event of an incident. Systems should be integrated into the national maritime infrastructure for coordinated responses across ports and maritime authorities. Additionally, redundancy and fail-safe mechanisms should be put in place to maintain operations during system failures. A significant investment is needed in communication networks, navigation systems, and port facilities to support autonomous vessel operations. These infrastructure improvements should align with international standards and regional needs, and collaboration with neighboring countries will help maximize the efficiency of these investments. To prepare Malaysia's maritime workforce for the challenges of autonomous shipping, comprehensive training programs should be developed. These programs should focus on operating autonomous technologies, following new safety protocols, and handling cybersecurity threats. While global advancements in autonomous shipping offer valuable lessons, Malaysia must adopt a tailored approach to leverage its unique geographical and economic position. By addressing critical gaps in cybersecurity and emergency response, Malaysia can position itself as a regional leader in autonomous shipping. The strategic adoption of these technologies not only enhances operational efficiency, but also strengthens Malaysia's role in global maritime trade, ensuring a sustainable and secure future for its maritime sector.

Additionally, given Malaysia's strategic position in the Straits of Malacca, regional cooperation with neighboring countries, especially Singapore, is essential. This collaboration should include joint training, information sharing, and the development of unified standards for autonomous shipping operations. By working together, countries can enhance security and operational efficiency in the region. Building public trust and industry acceptance is crucial for the successful adoption of autonomous vessels. Malaysia should launch public awareness campaigns to highlight the safety, economic, and environmental benefits of autonomous vessels, while addressing concerns about job displacement and safety. Transparent communication with stakeholders, including shipping

companies and oil firms, will create a supportive environment for the transition. Finally, Malaysia must create a clear regulatory framework for autonomous shipping. This should align with international standards, such as those from the IMO, and cover essential areas like security, operations, liability, and insurance. Clear regulations will help reduce uncertainty and encourage investment in the sector.

6. Conclusions

This study assessed Malaysia's readiness to integrate autonomous tanker vessels into its territorial waters, focusing on security and emergency response measures. The findings revealed significant gaps in stakeholder knowledge, cybersecurity preparedness, and emergency response capabilities. Despite these challenges, the study highlighted moderate confidence in technological readiness and the transformative potential of autonomous shipping for improving efficiency, reducing human error, and supporting environmental sustainability.

To address these challenges, the study recommends prioritizing targeted investments in advanced infrastructure, developing robust cybersecurity frameworks, and enhancing emergency response systems. Comprehensive training programs and regional collaboration are essential for addressing knowledge gaps and fostering a supportive environment for autonomous shipping. Public engagement and transparent communication must also be prioritized to build societal trust and industry acceptance. By implementing these measures, Malaysia can position itself as a regional leader in autonomous shipping, leveraging its strategic location in the Straits of Malacca to drive innovation and economic growth.

CRediT author statement

Rasyidah Mohd Sani: Conceptualization; Methodology; Software; Investigation; Visualization; Validation; **Mohammed Ismail Russtam Suhrab:** Data Curation; Writing - Original draft preparation; Supervision; Writing - Reviewing and Editing.

References

Asplund, F., & Ulfvengren, P. (2022). Engineer-centred design factors and methodological approach for maritime autonomy emergency response systems. *Safety, 8*(3), 1-26. https://doi.org/10.3390/safety8030054

Ben, F. M. A., Ukwandu, E., Hindy, H., Brosset, D., Bures, M., Andonovic, I., & Bellekens, X. (2022). Cybersecurity in the maritime industry: A systematic survey of recent advances and future trends. *Information, 13*(1), 22. https://doi.org/10.3390/info13010022

DNV. (2021). *YARA Birkeland: The world's first autonomous and zero-emission container ship*. Retrieved from https://www.dnv.com

Dougherty, J. R. (2021). *Autonomous vessels are becoming a commercial reality. The Maritime Executive*. Retrieved from https://maritime-executive.com

Haas, P., & Liss, C. (2020). Regional maritime agreements and autonomous vessel challenges in Southeast Asia. *Journal of Maritime Policy and Security, 5*(3), 185-203.

International Maritime Organization (IMO). (2018). *Regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS)*. Retrieved from https://www.imo.org

International Maritime Organization (IMO). (2022). *IMO seminar on development of a regulatory framework for maritime autonomous surface ships (MASS)*. Retrieved from https://www.imo.org/en/OurWork/Safety/Pages/MASS.aspx

Karlis, T., & Thanasis, A. (2018). Legislative challenges in the autonomous shipping industry. *Journal of Maritime Law, 15*(2), 49-63.

Le Goff, M. (2019). Cybersecurity threats in Southeast Asia's autonomous shipping industry. *Asia-Pacific Maritime Security Journal, 6*(1), 25-42.

Malaysia National Study Report on Autonomous Shipping. (2023). *Addressing challenges for autonomous vessels in Malaysia*. Government of Malaysia.

Maritime Institute of Malaysia (MIMA) & Maritime and Port Authority of Singapore (MPA). (2022). *Singapore-Malaysia maritime digitalisation dialogue: Joint insights*. Retrieved from https://www.mima.gov.my

Montewka, J. (2019). Risk assessment and emergency response for autonomous vessels. *Journal of Maritime Risk and Safety Management, 6*(4), 212-228.

Perera, L. P., Mo, B., & Soares, C. G. (2020). Maritime autonomous surface ships: Risk and trust assessment. *Ocean Engineering, 198*, 106936. https://doi.org/10.1016/j.oceaneng.2020.106936

Pietrzykowski, Z., Wołejsza, P., Nozdrzykowski, Ł., Borkowski, P., Banaś, P., Magaj, J., Chomski, J., Mąka, M., Mielniczuk, S., Pańka, A., Hatłas-Sowińska, P., Kulbiej, E., & Nozdrzykowska, M. (2022). The autonomous navigation system of a sea-going vessel. *Ocean Engineering, 261*, 112104. https://doi.org/10.1016/j.oceaneng.2022.112104

Rahman, B. (2022). Analyzing an appropriate autonomous vessel for the Southeast Asian route: From the view of seafarers. *Journal of Shipping and Trade, 7*(1), 21. https://doi.org/10.1186/s41072-022-00122-9

Stępień, B. (2023). Can a ship be its captain? Safe manning of autonomous and uncrewed vessels. *Marine Policy, 148*, 131. https://doi.org/10.1016/j.marpol.2022.105451

Tam, K., & Jones, K. (2019). MaCRA: A model-based framework for maritime cyber-risk assessment. *WMU Journal of Maritime Affairs, 18*, 129-163. https://doi.org/10.1007/s13437-019-00162-2

UNCTAD. (2018). *Review of maritime transport 2018*. UN, Geneva. Retrieved from https://www.un-ilibrary.org/content/books/9789210472418

Wang, X. (2020). Regional challenges in the integration of autonomous ships. *Journal of Southeast Asian Maritime Studies, 18*(4), 33-47.

Zhou, P., Zhu, Y., & Zhang, Y. (2022). The development status and trend of maritime autonomous surface ships: A review. *Ocean Engineering, 258*, 111756. https://doi.org/10.1016/j.oceaneng.2022.111756

Appendices

Appendix A: Survey questionnaire

The readiness of operating autonomous tanker vessels in Malaysia territorial waters (Security and emergency response)

Dear Participant,
Thank you for taking the time to participate in this survey. We are conducting research to explore feasibility of operating autonomous tanker vessels in Malaysia territorial waters in terms of security and emergency protocol. Your insights and expertise in the shipping industry are highly valuable in this endeavor. Please note that all responses provided will remain confidential. The information gathered will be used solely for research purposes.

Instructions:

- Please read each question carefully and select the most appropriate response or provide the requested information.
- If a question does not apply to your role or experience, feel free to select "N/A" or leave it blank. If you have any additional comments or insights, please feel free to provide them in the designated space.
- Thank you for your time and contribution to this important research.

* Indicates required question

1. NAME:

2. EMAIL

3. Sectors *
Mark only one oval.

- ☐ Port operators
- ☐ Shipping companies
- ☐ Maritime authorities
- ☐ Educators

Section 2: General Knowledge and Perception

General Knowledge and Perception aim to gather information about the respondents' understanding, awareness, and perceptions related to autonomous tanker vessels in Malaysia territorial waters.

4. How familiar are you with autonomous vessel technology? *
Mark only one oval.

	1	2	3	4	5	
Not Familiar	◯	◯	◯	◯	◯	Very Familiar

5. To what extent do you believe autonomous tanker vessels could provide benefits to the maritime industry? *
Mark only one oval.

	1	2	3	4	5	
No Benefits	◯	◯	◯	◯	◯	Very Significant Benefits

6. What are the main challenges or concerns you associate with the introduction of autonomous tanker vessels? *
Mark only one oval.

	1	2	3	4	5	
Not Concerned	◯	◯	◯	◯	◯	Very Concerned

7. How ready do you believe Malaysia's current technological infrastructure is to support autonomous tanker vessels? *
Mark only one oval.

	1	2	3	4	5	
Not Ready	◯	◯	◯	◯	◯	Fully Ready

8. Do you think Malaysia's existing infrastructure is sufficient to accommodate autonomous tanker vessels? *
Mark only one oval.

	1	2	3	4	5	
Insufficient	◯	◯	◯	◯	◯	Fully Insufficient

9. How aware are you of current initiatives or projects related to autonomous shipping or autonomous tanker vessels in Malaysia? *
Mark only one oval.

	1	2	3	4	5	
Not Aware	◯	◯	◯	◯	◯	Fully Aware

10. How do you perceive the potential economic impact of autonomous tanker vessels on Malaysia’s maritime industry?
Mark only one oval.

	1	2	3	4	5	
No Impact	◯	◯	◯	◯	◯	Very High Impact

11. How would you rate the level of public acceptance and trust in autonomous vessel technology in Malaysia territorial waters? *
Mark only one oval.

	1	2	3	4	5	
No Trust	◯	◯	◯	◯	◯	Complete Trust

12. What factors do you think would influence public perception and acceptance of autonomous tanker vessels? *
Mark only one oval.

	1	2	3	4	5	
No Influence	◯	◯	◯	◯	◯	Strong Influence

Section 3: Security Protocol

Note: Security protocols refer to measures implemented to protect autonomous tanker vessels from unauthorized access, cyber threats, piracy, or any security breaches.

13. How would you rate the current level of security measures for conventional tanker vessels in Malaysia's territorial waters? *
Mark only one oval.

	1	2	3	4	5	
Very Inadequate	◯	◯	◯	◯	◯	Very Adequate

14. How important is it to establish robust security protocols specifically for autonomous tanker vessels? *
Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

15. What do you perceive as the main security challenges for autonomous tanker vessels operating in Malaysia's territorial waters? *
Mark only one oval.

	1	2	3	4	5	
Not a Concern	◯	◯	◯	◯	◯	Very Serious Concern

16. How aware are you of the specific security regulations for autonomous vessel operations in Malaysia? *
Mark only one oval.

	1	2	3	4	5	
Not Aware	◯	◯	◯	◯	◯	Fully Aware

17. How prepared do you believe Malaysia’s maritime industry is in handling cybersecurity threats in relation to autonomous vessel operations? *
Mark only one oval.

	1	2	3	4	5	
Not Prepared	◯	◯	◯	◯	◯	Fully Prepared

18. How aware are you of the specific cybersecurity measures in place for autonomous vessel operations in Malaysia? *
Mark only one oval.

	1	2	3	4	5	
Not Aware	◯	◯	◯	◯	◯	Fully Aware

19. How effective do you think the current cybersecurity measures are in protecting autonomous tanker vessels in Malaysia? *
Mark only one oval.

	1	2	3	4	5	
Not Effective	◯	◯	◯	◯	◯	Very Effective

Section 4: Emergency Protocol

Note: Emergency protocols encompass plans and procedures to handle accidents, malfunctions, natural disasters, or any unforeseen events related to autonomous tanker vessels.

20. How critical do you think it is to establish comprehensive emergency response protocols for autonomous tanker vessels? *

Mark only one oval.

	1	2	3	4	5	
Not Critical	◯	◯	◯	◯	◯	Extremely Critical

21. How confident are you in the current emergency response capabilities and protocols for incidents involving autonomous tanker vessels in Malaysia territorial waters? *

Mark only one oval.

	1	2	3	4	5	
Not Confident	◯	◯	◯	◯	◯	Very Confident

22. What do you think are the key aspects that need to be addressed in the emergency response protocols for autonomous tanker vessels? *

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

23. How would you rate the existing emergency response capabilities and protocols for incidents involving autonomous tanker vessels in Malaysia territorial waters? *

Mark only one oval.

	1	2	3	4	5	
Very Poor	◯	◯	◯	◯	◯	Excellent

Section 5: Additional Comments

24. In your opinion, what are the primary benefits of operating autonomous tanker vessels in Malaysia territorial waters? Please select up to three options: *

Tick all that apply.

- ☐ Improved operational efficiency
- ☐ Reduced human error
- ☐ Lower maintenance costs
- ☐ Enhanced safety
- ☐ Environmental benefits
- ☐ Greater navigational accuracy
- ☐ Other (please specify):

25. Other (please specify):

26. Please provide any additional comments or suggestions related to the feasibility of operating autonomous tanker vessels in Malaysia territorial waters in terms of security and emergency protocol.

Thank you for your participation and valuable input! Your responses will greatly contribute to our research on the readiness of operating autonomous tanker vessels in Malaysia territorial waters (Security and emergency response).