International Journal of Education, Vocational and Social Science
https://e-journal.citakonsulindo.or.id/index.php/IJEVSS
E-ISSN : 2963 4954
IJEVSS

Resilient Surveillance Architecture for Critical Maritime Routes: A Case Study of the Malacca Strait under Extreme Weather Scenarios

Aldy Surya Alriandi[1]
[1]Indonesia Defense University
Abdul Rivai Ras[2]
[2]Indonesia Defense University
Moch Jurianto[3]
[3]Indonesia Defense University

Corresponding Author: aldysurya42@gmail.com

Abstract

The maritime sector's transition to Maritime 4.0, integrating digital technologies like IoT and AI, enhances operational efficiency but introduces complex cyber-risks. This deep interconnectivity expands the cyber-attack surface, threatening global supply chains, often exploited via human error. Vital chokepoints, such as the Strait of Malacca, face these advanced threats, which are exacerbated by weak governance and regulatory gaps. Concurrently, an escalating marine environmental crisis, driven by intensive maritime activities and climate change (e.g., extreme weather), poses existential threats and operational risks. Current surveillance architectures lack resilience to these extreme weather events, creating dangerous security vacuums. This essay proposes a conceptual framework for a resilient maritime surveillance architecture in the Malacca Strait, integrating proactive risk management, layered redundancy, and adaptive governance. Aligned with the Maritime 5.0 vision and a Sustainable Blue Economy, this framework emphasizes that marine ecosystem health is fundamental to long-term security.

Keywords: Maritime Security; Malacca Strait; Resilient Surveillance; Extreme Weather; Maritime 4.0; Blue Economy

INTRODUCTION

The maritime sector is the lifeblood of the global economy, facilitating over 80% of world trade volume and serving as a vital foundation for a complex and interconnected international

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

supply chain. Over the last two decades, the industry has undergone a fundamental transformation driven by a wave of technological innovation known as Maritime 4.0. This new paradigm is characterized by the deep integration of digital technologies, automation, and pervasive data interconnectivity. According to a bibliometric analysis by Razmjooei et al. (2023), research on Maritime 4.0 has grown rapidly, with a primary focus on implementing the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data to enhance efficiency.

However, behind this promise of efficiency lies an increasingly complex and layered risk landscape. The deep interconnectivity between operational technology (OT) and information technology (IT) drastically expands the attack surface for threat actors. A high dependency on these integrated digital systems means that a single failure—whether caused by a technical glitch, human error, or a deliberate cyber-attack—could trigger a crippling domino effect across the global supply chain. A systematic literature review by Bolbot et al. (2022) identified that research in maritime cybersecurity is concentrated on developing risk assessment techniques and intrusion detection tools, implicitly acknowledging the industry's race against time to secure itself from new vulnerabilities.

The importance of securing global trade becomes even more critical when focused on maritime chokepoints. The Strait of Malacca, the primary case study for this paper, is the most representative example of such a chokepoint, serving as the main artery for approximately one-third of all global trade. The level of maritime connectivity has been shown to have a strong positive correlation with a nation's GDP and logistical performance (Bouazza et al., 2023), underscoring the vital importance of maintaining operational fluidity in the Strait for regional and global economic stability.

In the era of Maritime 4.0, the spectrum of threats has become multidimensional. While physical threats like piracy remain a concern, non-physical threats are now at the forefront. Cybersecurity has emerged as a significant challenge, with research by Park et al. (2023) finding that malware and human error are the highest sources of cyber risk. This technological shift has also sparked a fundamental debate about the future role of humans. Shahbakhsh et al. (2021) critique the technology-centric paradigm of Maritime 4.0, proposing instead a "Maritime 5.0" vision that emphasizes a synergistic collaboration between humans and machines. This vision aligns with the growing awareness of social sustainability in the sector, as Karakasnaki et al. (2023) argue that the well-being of seafarers is a multidimensional construct essential for safe and resilient operations.

The complexity of these challenges is amplified by a significant risk multiplier:

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

environmental uncertainty. As Ksciuk et al. (2023) conclude, uncertainty arising from weather conditions is a fundamental challenge in voyage planning. In the context of global climate change, extreme weather phenomena—such as tropical storms and transboundary haze—are projected to increase in frequency and intensity, posing a strategic threat capable of paralyzing entire shipping corridors. To counter this, the industry is developing more advanced risk analysis methods. Approaches using Fuzzy Logic and Evidential Reasoning show promise for assessing supply chain risks with subjective or incomplete data (Jiang et al., 2023). Concurrently, the use of supervised machine learning for maritime risk analysis is expanding, though it still faces challenges related to data availability and model transparency (Rawson & Brito, 2023).

This is where the critical research gap that this paper addresses is located. Modern maritime surveillance architectures are generally designed for optimal function under normal to moderate conditions. The fundamental question, crucial for future maritime security, remains largely unanswered: how resilient is this surveillance architecture when faced with the pressure of extreme weather scenarios? A major storm can not only increase navigational risks but also potentially disable the vital components of the surveillance architecture itself—from radar performance degradation to power outages on shore—creating a "security vacuum" at the most critical moment. This transforms extreme weather from a safety issue into an acute maritime security problem.

Therefore, this paper aims to formulate and propose a conceptual framework for a resilient maritime surveillance architecture for the Strait of Malacca. This framework is specifically designed to maintain operational integrity and effectiveness in the face of extreme weather scenarios, integrating proactive risk management, layered system redundancy, data decentralization, and adaptive governance.

METHODS

This study employs a qualitative approach, specifically a systematic literature review, to construct a conceptual framework. This method was chosen to synthesize existing knowledge from various disciplines—including maritime security, information technology, environmental science, and governance—to identify gaps and propose an innovative solution to a complex problem. The research process involved several stages:

1. Literature Identification: A search was conducted in academic databases such as Scopus, ScienceDirect, and Google Scholar using keywords including "maritime security,"

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

"Maritime 4.0," "cybersecurity," "Malacca Strait," "extreme weather," "resilience," and "blue economy."

2. Selection and Analysis: Relevant articles, journals, and reports were selected based on inclusion criteria focusing on digital transformation in the maritime sector, risk analysis, security governance, and the impacts of climate change. Each source was analyzed to extract key arguments, findings, and methodologies.
3. Thematic Synthesis: The collected information was then condensed and categorized into major themes: (a) the new paradigm of maritime security in the digital era, (b) governance gaps and risk management, (c) the marine environmental crisis as an existential threat, and (d) the vision of a Sustainable Blue Economy.
4. Framework Development: Based on the thematic synthesis, a conceptual framework for a resilient surveillance architecture was formulated. This framework was built by integrating principles from the existing literature, such as system redundancy, data decentralization, proactive risk management, and adaptive governance, to address the identified research gap: the lack of resilience in maritime surveillance architectures against extreme weather.

This approach allows the research to build a robust, evidence-based argument without generating primary data, consistent with the conceptual and theoretical nature of the study.

RESULTS AND DISCUSSION

Digital Transformation and the New Paradigm of Maritime Security

The digital transformation towards Maritime 4.0 has fundamentally reshaped the landscape of maritime operations and security, driven by the massive adoption of technologies such as IoT, AI, and Big Data to create a more efficient ecosystem (Razmjooei et al., 2023). However, the deep interconnectivity between operational technology (OT) and information technology (IT) creates a "double-edged sword." On one hand, real-time data enables better decision-making; on the other hand, it opens the door to a previously unimaginable spectrum of cyber threats, a vulnerability exacerbated by the fact that maritime digital infrastructure is often built on legacy systems that were not designed with cybersecurity in mind.

Critical systems such as the Automatic Identification System (AIS), Global Positioning System (GPS), and Electronic Chart Display and Information System (ECDIS), which form the backbone of modern navigation, have become primary targets for jamming, spoofing, and malware injection attacks (Akpan et al., 2022). A successful attack on one of these systems could not only cause misinformation but also loss of ship control, potentially leading to collisions or

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

groundings that result in massive ecological damage and economic losses. In the face of these threats, a systematic risk assessment methodology is crucial. Research in this field has grown rapidly, with a focus on risk assessment techniques and intrusion detection systems (Bolbot et al., 2022). An innovative framework combining

Failure Mode and Effects Analysis (FMEA) and Rule-based Bayesian Network (RBN) found that malware and human factors—such as lack of awareness or training—are the biggest contributors to cyber risk (Park et al., 2023). This underscores the fundamental truth that no matter how advanced the technology, humans remain the key element, acting as both the frontline of defense and the weakest link.

This complexity is further compounded by cultural differences in risk perception. Practitioners in Asia tend to adopt a more holistic approach, viewing cybersecurity as an integral part of overall business risk management, while their European counterparts often see it as an isolated technical issue for the IT department (Karamperidis et al., 2021). This paradigm shift has significant implications for the effectiveness of security policies, as a holistic approach is more likely to be proactive and integrated. As threats increase, innovations in surveillance technology such as

High-Frequency Surface Wave Radar (HFSWR) offer promising solutions. HFSWR can address significant blind spots created by “dark” or non-cooperative ships that deliberately turn off their AIS transponders to avoid detection. A study in the Gulf of Guinea demonstrated HFSWR's ability to detect and track such vessels, even identifying suspicious movement patterns associated with illegal oil smuggling and piracy preparations. This technology has the potential to transform surveillance from a passive and reactive system into a more predictive and proactive one (Nikolic et al., 2023).

However, amid these technological advances, criticism has emerged against the Maritime 4.0 paradigm for being overly focused on automation, with the argument that it risks neglecting the irreplaceable intelligence, intuition, and adaptability of humans (Shahbakhsh et al., 2021). Instead, an evolution toward Maritime 5.0 is proposed, positioning humans as collaborative partners in socio-technical systems, not merely as operators. In this vision, sailors act as supervisors of intelligent systems, problem solvers, and critical decision-makers when technology fails (Shahbakhsh et al., 2021). This vision is particularly relevant for unforeseen scenarios such as extreme weather, where human situational assessment becomes the primary determinant between safety and disaster. Concurrently, the application of

Machine Learning (ML) for risk analysis shows great potential in predicting accidents by

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

analyzing millions of data points from AIS, weather reports, and ship inspection records. However, this field still faces significant challenges related to data quality and the "black-box problem," where the lack of transparency in ML model decision-making processes remains a major barrier to adoption in safety-critical applications, where understanding why a decision was made is as important as the accuracy of the prediction itself (Rawson & Brito, 2023).

Governance, Risk, and Resilience in a Multidimensional Context

The effectiveness of surveillance architecture depends heavily on the surrounding governance, risk management, and resilience frameworks. A persistent challenge is the significant gap between international regulations such as the ISPS Code and their often weak implementation at the national level, which can be eroded by poor coastal state governance (Ávila-Zúñiga Nordfjeld & Dalaklis, 2021). A case study in the Gulf of Mexico shows that attacks on ships are not reported significantly and port security levels are not improved despite numerous incidents, a failure rooted in weak maritime governance and the absence of a coherent national maritime security policy (Ávila-Zúñiga Nordfjeld & Dalaklis, 2021). Even in developed countries like Sweden, compliance barriers are often caused by low threat perceptions and a "minimum compliance culture" focused on administrative fulfillment rather than a proactive "safety culture" (Ringsberg & Cole, 2020).

This governance gap is exacerbated by the phenomenon of "sea blindness," a condition where a country fails to recognize the importance of its maritime domain and the vulnerability of critical underwater infrastructure such as data cables (Bueger & Liebetrau, 2023; McCabe & Flynn, 2024). The case of Ireland, a vital hub for trans-Atlantic data cables with insufficient capacity to protect them, illustrates how this vulnerability can affect an entire continent (McCabe & Flynn, 2024). Additionally, policy fragmentation, where safety, security, and environmental issues are handled by different and uncoordinated agencies, also leads to reactive policies driven by past incidents rather than proactive ones based on comprehensive risk analysis (Turedi & Ozer-Caylan, 2021).

In risk management, analysis has evolved from qualitative approaches to more sophisticated data-driven quantitative models. Data-driven Bayesian Networks (BN), for example, can be used to analyze global maritime accident data to identify key risk factors and model their probabilistic relationships, enabling stakeholders to conduct "what-if" scenario analyses (Li et al., 2023). For supply chain risks with subjective and uncertain data, a hybrid approach combining Fuzzy Logic and Evidential Reasoning has proven superior, as demonstrated in a study on the

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Maritime Silk Road identifying fuel prices as the most significant risk factor (Jiang et al., 2023). The COVID-19 pandemic served as a real-world resilience test, highlighting that companies with better supply chain digitalization and visibility proved more adaptive (Wang et al., 2024). However, there remains a lack of empirical research directly linking disruption management strategies to improved organizational performance, indicating the need for future models that integrate risk management, Business Continuity Management, and lean-agile principles (Nguyen et al., 2023). Although academic solutions for managing uncertainty, particularly from weather, already exist, their adoption by industry remains low, except for weather routing (Ksciuk et al., 2023). This forces operators to face a difficult dilemma between the short-term economic benefits of schedule recovery and the long-term environmental damage from increased emissions (Bueger & Liebetrau, 2023).

Geopolitical dimensions also play a significant role, with chokepoints like the Malacca Strait becoming strategic competition arenas between nations (Agastia, 2021). Complex maritime boundary disputes, such as in the Mediterranean between Greece and Turkey (Yildiz, 2020) and delicate negotiations over Exclusive Economic Zones between Indonesia and Timor-Leste (Sunyowati et al., 2023), add another layer of tension. Critically, there is a growing challenge to the dominant narrative of maritime security, which raises the fundamental question: “Security for whom?” (Okafor-Yarwood & Onuoha, 2023). The global maritime security agenda is often driven by the interests of major nations to protect their trade routes, often at the expense of the human security of coastal communities facing poverty and environmental degradation (Okafor-Yarwood & Onuoha, 2023). This approach risks “securitizing” economic issues such as illegal fishing into militaristic problems that fail to address the root causes (Beseng & Malcolm, 2021) and often overlook the protection of human rights at sea (Galani, 2020). Security interventions, even when framed with multilateral narratives, may be driven primarily by commercial interests (Pugliese, 2023). This calls for a critical re-evaluation to build a truly inclusive and sustainable maritime security framework (Li, 2023).

Sustainable Development and the Marine Environmental Crisis

The discourse on modern maritime security faces an inherent dilemma in balancing the drive for economic development with worsening environmental crises. Maritime connectivity is a key pillar of development. In eastern Indonesia, for example, logistical inefficiencies such as high transportation costs due to limited infrastructure have been shown to have a negative impact on per capita GDP and increase the cost of living (Amin et al., 2021). Similarly, a country's shipping

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

route connectivity is positively correlated with its economic growth (Bouazza et al., 2023). However, sustainable development must also include the social welfare of seafarers—a multidimensional concept that encompasses physical and mental health, work functionality, and cultural aspects (Karakasnaki et al., 2023) —as well as the empowerment of coastal communities through programs rooted in local culture, such as ecotourism, which can enhance entrepreneurial attitudes and environmental awareness (Zamzami & Effendi, 2023). Even national infrastructure development, such as naval bases, has important defense and security dimensions beyond its commercial aspects (Amelia et al., 2022).

However, intensive maritime activities impose significant environmental costs. These include macroplastic pollution, exacerbated by low public awareness and inadequate waste management infrastructure (Balogun et al., 2021), as well as microplastics that have been found to enter the marine food web, ultimately posing risks to human health (Alves et al., 2021). Furthermore, “invisible” pollution such as underwater noise from ships is increasing globally, which can disrupt communication and behavior among marine mammals (Jalkanen et al., 2022). There are also direct conflicts between high-traffic shipping lanes and critical marine mammal habitats, with areas such as the Malacca Strait identified as a global hotspot with high risks of ship strikes and noise pollution that directly threaten vulnerable populations (Ghahremanloo et al., 2024). Effective enforcement of anti-pollution regulations such as MARPOL along major shipping routes remains a significant and ongoing challenge (Estiningtyas et al., 2024).

This crisis is critically exacerbated by climate change, which has now become an existential threat. Rising sea levels and more intense storms directly endanger coastal transportation infrastructure such as ports, which are the arteries of global trade (Macdonald et al., 2024). Concurrently, rising temperatures and extreme rainfall significantly degrade water quality in estuaries by reducing dissolved oxygen, causing saltwater intrusion into freshwater aquifers, and increasing pollutant runoff from land (Song et al., 2024). These impacts create a vicious cycle: coastal flooding not only damages infrastructure but also carries land-based pollutants into the sea, exacerbating water contamination and ecosystem damage.

In the face of this dual challenge, the paradigm of Sustainable Blue Economy has emerged as the way forward, advocating for the ocean to be managed as a whole ecosystem, not just as a resource to be exploited (Langer et al., 2022). This requires a new form of integrated, science-based governance with the ability to measure and manage complex trade-offs between economic and environmental objectives, using analytical models to prevent irreversible degradation (Rahayu et al., 2023). These principles must also be integrated into operational decision-making,

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

providing transparent tools to weigh the economic benefits against the environmental costs of actions such as accelerating ships after delays (Bueger & Liebetrau, 2023). Ultimately, building resilience in the Malacca Strait means building an ecologically intelligent system, where the health and stability of marine ecosystems are understood as fundamental prerequisites for long-term security and prosperity.

CONCLUSIONS

The maritime sector's digital transformation towards Maritime 4.0 presents a fundamental paradox: while technologies like IoT and AI offer unprecedented operational efficiency, they simultaneously introduce complex systemic risks. The deep interconnectivity of ship systems expands the cyber-attack surface, where human error and malware pose significant threats. This technological vulnerability is compounded by persistent governance gaps, where weak national implementation of international security codes and a pervasive "sea blindness" to critical infrastructure leave the global supply chain exposed. This creates a highly complex security environment where the benefits of digitalization are in a constant battle with its inherent risks, a situation that current security paradigms struggle to adequately address.

This complex risk landscape is critically amplified by the escalating marine environmental crisis, particularly the threat of extreme weather driven by climate change. This paper argues that extreme weather is no longer a peripheral safety issue but a central, strategic threat that can disable the very surveillance architectures designed to ensure maritime security. The potential for radar disruption, communications failure, and power outages during a major storm creates a "security vacuum" at the moment of highest risk. This exposes a critical research gap: modern surveillance systems, designed for normal operating conditions, lack a proven framework for resilience against the severe, systemic shocks of an increasingly volatile natural environment.

To address this gap, this paper proposes a conceptual framework for a resilient maritime surveillance architecture specifically designed to maintain operational integrity during extreme weather scenarios. Moving beyond a purely technological solution, this framework integrates proactive risk management, layered redundancy, data decentralization, and adaptive governance. By doing so, it aligns with the forward-looking visions of Maritime 5.0, which re-centers the collaborative role of humans, and the Sustainable Blue Economy, which posits that ecological health is the foundation of long-term economic prosperity. Ultimately, this framework provides a strategic pathway for stakeholders to build a security ecosystem that is not only technologically

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

advanced but fundamentally resilient and ecologically intelligent.

REFERENCES

Agastia, I. G. B. D. (2021). Maritime security cooperation within the ASEAN institutional framework: A gradual shift towards practical cooperation. *Journal of ASEAN Studies*, *9*(1), 25–48. https://doi.org/10.21512/jas.v9i1.6919

Akpan, F., Bendiab, G., Shiaeles, S., Karamperidis, S., & Michaloliakos, M. (2022). Cybersecurity challenges in the maritime sector. *Network*, *2*(1),

Alves, T. M., Kokinou, E., Ekström, M., Nikolaidis, A., Georgiou, G. C., & Milios, A. (2021). Scientific, societal and pedagogical approaches to tackle the impact of climate change on marine pollution. *Scientific Reports*, *11*(1), 2927. https://doi.org/10.1038/s41598-021-82421-y

Amelia, P., Lathifah, A., & Yasa, I. N. A. (2022). Analysis of the impact of maritime sector development in supporting Indonesian Navy Ship operations. *Procedia Computer Science*, *197*, 317–325. https://doi.org/10.1016/j.procs.2021.12.146

Amin, C., Mulyati, H., Anggraini, E., & Kusumastanto, T. (2021). Impact of maritime logistics on archipelagic economic development in eastern Indonesia. *The Asian Journal of Shipping and Logistics*, *37*(3), 157–164. https://doi.org/10.1016/j.ajsl.2021.01.004

Ávila-Zúñiga Nordfjeld, A., & Dalaklis, D. (2021). Repercussions of a weak ocean governance and a non-existent maritime security policy: The resurgence of piracy and Armed Robbery in the Gulf of Mexico. *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, *5*(2), 62–73. https://doi.org/10.1080/25725084.2021.1925461

Balogun, A.-L., Yekeen, S. T., Pradhan, B., & Wan Yusof, K. B. (2021). Oil spill trajectory modelling and environmental vulnerability mapping using GNOME model and GIS. *Environmental Pollution*, *268*(Part B), 115935. https://doi.org/10.1016/j.envpol.2020.115935

Beseng, M., & Malcolm, J. A. (2021). Maritime security and the securitisation of fisheries in the Gulf of Guinea: experiences from Cameroon. *Conflict, Security & Development*, *21*(5), 517–539. https://doi.org/10.1080/14678802.2021.1985848

Bolbot, V., Kulkarni, K., Brunou, P., Valdez Banda, O., & Musharraf, M. (2022). Developments and research directions in maritime cybersecurity: A systematic literature review and bibliometric analysis. International Journal of Critical Infrastructure Protection, 39, 100571. https://doi.org/10.1016/j.ijcip.2022.100571

Bouazza, S., Benmamoun, Z., & Hachimi, H. (2023). Maritime Bilateral Connectivity Analysis for Sustainable Maritime Growth: Case of Morocco. Journal of Marine Science and

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Engineering, 11(2), 444. https://doi.org/10.3390/jmse11020444

Bueger, C., & Liebetrau, T. (2023). Critical maritime infrastructure protection: What's the trouble? *Marine Policy*, *155*, 105772. https://doi.org/10.1016/j.marpol.2023.105772

Estiningtyas, W., Surmaini, E., Suciantini, Susanti, E., Mulyani, A., Kartiwa, B., Sumaryanto, Perdinan, Apriyana, Y., & Alifia, A. D. (2024). Analysing food farming vulnerability in Kalimantan, Indonesia: Determinant factors and adaptation measures. *PLOS ONE*, *19*(1), e0296262. https://doi.org/10.1371/journal.pone.0296262

Galani, S. (2020). Assessing Maritime Security and Human Rights: The Role of the EU and its Member States in the Protection of Human Rights in the Maritime Domain. *The International Journal of Marine and Coastal Law*, *35*(2), 325–347. https://doi.org/10.1163/15718085-23441006

Ghahremanloo, M., Choi, Y., & Singh, D. (2024). Deep learning bias correction of GEMS tropospheric NO2: A comparative validation of NO2 from GEMS and TROPOMI using Pandora observations. *Environment International*, *190*, 108818. https://doi.org/10.1016/j.envint.2024.108818

Jalkanen, J.-P., Johansson, L., Andersson, M. H., Majamäki, E., & Sigray, P. (2022). Underwater noise emissions from ships during 2014–2020. *Environmental Pollution*, *311*, 119766. https://doi.org/10.1016/j.envpol.2022.119766

Jiang, M., Liu, Y., Lu, J., Shang, X., & Zhang, Y. (2023). Risk assessment of maritime supply chains within the context of the Maritime Silk Road. Reliability Engineering & System Safety, 231, 108960. https://doi.org/10.1016/j.ress.2022.108960

Karakasnaki, M., Pantouvakis, A., & Vlachos, I. (2023). Maritime social sustainability: Conceptualization and scale development. Marine Policy, 147, 105374. https://doi.org/10.1016/j.marpol.2022.105374

Karamperidis, S., Kapalidis, C., & Watson, T. (2021). Maritime cyber security: A global challenge tackled through distinct regional approaches. *Journal of Marine Science and Engineering*, *9*(12), 1323. https://doi.org/10.3390/jmse9121323

Ksciuk, J., Kuhlemann, S., Tierney, K., & Koberstein, A. (2023). Uncertainty in maritime ship routing and scheduling: A Literature review. European Journal of Operational Research, 308(2), 499-524. https://doi.org/10.1016/j.ejor.2022.08.006

Langer, J., Simanjuntak, S., Pfenninger, S., Jarquin Laguna, A., Lavidas, G., Polinder, H., Quist, J., Rahayu, H. P., & Blok, K. (2022). How offshore wind could become economically attractive in low-resource regions like Indonesia. *iScience*, *25*(9), 104945.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

https://doi.org/10.1016/j.isci.2022.104945

Li, H., Ren, X., & Yang, Z. (2023). Data-driven Bayesian network for risk analysis of global maritime accidents. Reliability Engineering & System Safety, 230, 108938. https://doi.org/10.1016/j.ress.2022.108938

Li, L. (2023). Building Up a Sustainable Path to Maritime Security: An Analytical Framework and Its Policy Applications. *Sustainability*, *15*(8), 6757. https://doi.org/10.3390/su15086757

Macdonald, A., McDonald, J., Schmitt, T., Cai, H., Ceponis, J., Cullen, C., Dutta, P., Ruiz, A. C., & Stevens, A. (2024). New York State Climate Impacts Assessment Chapter 09: Transportation. *Annals of the New York Academy of Sciences*, *1542*(1), 501–560. https://doi.org/10.1111/nyas.15198

McCabe, R., & Flynn, B. (2024). Under the radar: Ireland, maritime security capacity, and the governance of subsea infrastructure. *European Security*, *33*(2),

Nguyen, T.-T., Tran, D. T. M., Duc, T. T. H., & Thai, V. V. (2023). Managing disruptions in the maritime industry – a systematic literature review. *Maritime Business Review*, *8*(2), 170–190. https://doi.org/10.1108/MABR-09-2021-0072

Nikolic, D., Stojkovic, N., Puzovic, S., Popovic, Z., Stojiljkovic, N., Grbic, N., & Orlic, V. D. (2023). Increasing maritime safety and security in the off-shore activities with HFSWRs as primary sensors for risk assessment. *Journal of Marine Science and Engineering*, *11*(6), 1167. https://doi.org/10.3390/jmse11061167

Okafor-Yarwood, I. M., & Onuoha, F. C. (2023). Whose security is it? Elitism and the global approach to maritime security in Africa. *Third World Quarterly*, *44*(5), 946–966. https://doi.org/10.1080/01436597.2023.2167706

Park, C., Kontovas, C., Yang, Z., & Chang, C. (2023). A BN driven FMEA approach to assess maritime cybersecurity risks. Ocean & Coastal Management, 231, 106394. https://doi.org/10.1016/j.ocecoaman.2022.106394

Pugliese, G. (2023). The European Union's Security Intervention in the Indo-Pacific: Between Multilateralism and Mercantile Interests. *Journal of Intervention and Statebuilding*, *17*(1), 76–98. https://doi.org/10.1080/17502977.2022.2118425

Rahayu, Y. P., Kusumaningtyas, M. A., Daulat, A., Rustam, A., Suryono, D. D., Salim, H. L., Ati, R. N. A., Sudirman, N., Kepel, T. L., Hutahaean, A. A., & Adi, N. S. (2023). Sedimentary seagrass carbon stock and sources of organic carbon across contrasting seagrass meadows in Indonesia. *Environmental Science and Pollution Research*, *30*(42), 97754–97764. https://doi.org/10.1007/s11356-023-29257-3

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Rawson, A., & Brito, M. (2023). A survey of the opportunities and challenges of supervised machine learning in maritime risk analysis. Accident Analysis & Prevention, 181, 106935. https://doi.org/10.1016/j.aap.2023.106935

Razmjooei, D., Alimohammadlou, M., Ranaei Kordshouli, H., & Askarifar, K. (2023). Industry 4.0 research in the maritime industry: a bibliometric analysis. WMU Journal of Maritime Affairs, 22(3), 385-416. https://doi.org/10.1007/s13437-022-00298-8

Ringsberg, A. H., & Cole, S. (2020). Maritime security guidelines: a study of Swedish ports' perceived barriers to compliance. *Maritime Policy & Management*, *47*(3), 388–401. https://doi.org/10.1080/03088839.2020.1711977

Shahbakhsh, M., Emad, G. R., & Cahoon, S. (2021). Industrial revolutions and transition of the maritime industry: The case of Seafarer's role in autonomous shipping. The Asian Journal of Shipping and Logistics, 37(4), 330-338. https://doi.org/10.1016/j.ajsl.2021.05.003

Song, R., Spadon, G., Pelot, R., Matwin, S., & Soares, A. (2024). Enhancing global maritime traffic network forecasting with gravity-inspired deep learning models. *Scientific Reports*, *14*(1), 16665. https://doi.org/10.1038/s41598-024-67552-2

Sunyowati, D., Ariadhi, P. P. P., Romadhona, M. K., & Alfadhel, A. B. B. (2023). Indonesia-Timor Leste maritime boundaries on Exclusive Economic Zone: Equitable principle. *Lex Scientia Law Review*, *7*(1), 347-372. https://doi.org/10.15294/lesrev.v7i1.66126

Turedi, O., & Ozer-Caylan, D. (2021). Developing a grounded theory of national maritime policies based on safety, security and environment. *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, *5*(2), 84–97

Wang, S., Wang, Y., & Lai, C. (2024). Connectivity reliability evaluation and most reliable shipping route choice in a seaborne crude oil network. *Heliyon*, *10*(15), e36295. https://doi.org/10.1016/j.heliyon.2024.e36295

Yildiz, E. (2020). The conflict between Greece and Turkey in the Mediterranean sea (International maritime law study). *Jurnal Hukum UNISSULA*, *36*(2). https://doi.org/10.26532/jh.v36i2.11393

Zamzami, L., & Effendi, N. (2023). Cultural and entrepreneurial attitudes of fishermen involved in the production of fishery products in West Sumatra, Indonesia: Implications for marine resource conservation areas in village development. *Journal of Infrastructure, Policy and Development*, *7*(3), 2629. https://doi.org/10.24294/jipd.v7i3.2629

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License