

Maritime Security with Geospatial Integration For Indonesia's Archipelagic Sea Lanes (ALKI)

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Abstract

Advances in digital technology have revolutionized the maritime sector through the use of Automatic Identification Systems (AIS), artificial intelligence (AI), remote sensing, and geospatial analytics, which are increasingly important in supporting Maritime Domain Awareness (MDA). Various studies show that AIS now functions as a strategic data source for predictive analytics, risk mapping, and even detecting anomalous vessel behavior, while big data and AI drive energy efficiency, logistics optimization, and intelligent navigation systems. Various methodological innovations can enable the integration of heterogeneous data to produce more accurate ship accident risk maps, while the combination of AIS with satellite imagery strengthens the detection of illegal activities such as IUU fishing in remote areas. Furthermore, the application of machine learning and deep learning algorithms has proven effective in detecting data manipulation and abnormal navigation patterns, thus strengthening early detection and rapid response systems. For Indonesia, which has strategic shipping lanes, the integration of these technologies is highly relevant to strengthen maritime surveillance, enhance maritime security, and maintain sovereignty amidst the region's geopolitical dynamics.

Keywords: Maritime Security, Geospatial Intelligence, Archipelagic Sea Lanes (ALKI), Maritime Surveillance, Automatic Identification System (AIS), Remote Sensing



INTRODUCTION

Indonesia is the world largest archipelagic country, with over 17.000 islands and a sea area covering approximately 70% of it's total territory. This vast area presents Indonesia with complex challenges in maintaining maritime security, particularly in strategic areas such as the Indonesian Archipelagic Sea Lanes (ALKI). ALKI itself is an international shipping lane established and regulated by the United Nations Convention on the Law of the Sea (UNCLOS 1982), serving as the main route for international vessels passing between the Indian Ocean and the Pacific Ocean. ALKI's strategic role is not only limited to its function as a vital global trade route, international logistics flows, and supporting regional stability, but also serves as a crucial point in regional security dynamics. This significant position also makes ALKI as a vulnerable point for various forms of maritime security threats such as privacy violations, illegal trade, IUU fishing, piracy and armed robbery as well as potential infiltration by non-state actors (Schofield, 2023).

In the context of an archipelagic nation like Indonesia, which enjoys a strategic position along international shipping lanes, maritime border security approaches can no longer rely solely on conventional methods. Conventional approaches to maritime security, such as traditional patrols and radar surveillance, are still unable to address the complexity of real-time and multidimensional threats. The application of digital technology is crucial to support surveillance, decision-making, and risk mitigation in national waters. The complex dynamics of ship traffic, the high potential for maritime law violations, and the limited physical surveillance in high-seas areas demand a maritime information monitoring and management system. Indonesia's vast and dynamic maritime territory requires an accurate, integrated, and high-tech security surveillance and response system. This can be achieved by integrating modern geospatial-based technologies, such as the Automatic Identification System (AIS), remote sensing, and artificial intelligence (AI). Currently, the use of artificial intelligence (AI) has become a crucial component in data-driven decision-making as a relevant rapid response system to strengthen maritime border security (Munim et al., 2020).

The development of digital technology in the current industrial revolution era has driven the integration of big data and artificial intelligence (AI), which has brought significant changes in various fields, including the maritime sector. Through a bibliometric approach, technologies such as machine learning and predictive analytics are used to identify abnormal shipping patterns, predict potential security threats, and improve the efficiency of maritime logistics systems. In the realm of maritime security, AI plays a crucial role in quickly and accurately processing various types of data, from AIS information and satellite imagery to marine sensor data, thus supporting data-



driven decision-making. Furthermore, AI is capable of building predictive models that can anticipate threats based on historical patterns and vessel movements. In the Indonesian context, the application of this technology is highly urgent, given the vast national waters that remain under-monitored due to limited human resources and logistics infrastructure (Munim et al., 2020).

The AIS data method or automatic identification system, is a navigation tool that uses maritime geospatial features to automatically recognize ship traffic patterns or ship tracking systems, providing information such as ship identification and position. With this maritime big data analysis, the system will recognize shipping patterns that can be distinguished from abnormal or unusual ship activity, such as the presence of ships that turn off their AIS, which allows for sudden route changes or ships stopping in prohibited areas to avoid detection, as well as anticipating illegal activities such as transshipment on the high seas, such as in the ALKI area. The use of this system is highly relevant for Indonesia, given the vastness of Indonesian waters and the often difficult nature of direct surveillance. The integration of AIS data and maritime spatial features can strengthen the detection system for foreign vessels attempting to access the ALKI area without permission, thereby increasing oversight of violations of Indonesia's maritime sovereignty (Li et al., 2024).

Modern surveillance utilizes the Automatic Identification System (AIS), an automated tracking system used by ships to transmit real-time location, speed, and identity data, making it a crucial system in maritime surveillance. According to Meyers et al. (2021), a bibliometric study shows that research on AIS continues to grow and has become a crucial component in various maritime studies, including security, maritime traffic management, and environmental protection. AIS can analyze shipping behavior, but still faces challenges such as data manipulation by ships (spoofing) and limited signal coverage in remote waters. AIS has become a crucial component in the development of Maritime Domain Awareness (MDA), as it provides real-time ship navigation data that can be used by maritime security authorities to detect potential violations. However, challenges remain, such as manipulation of AIS signals by certain ships, limited signal coverage in high seas, and a lack of data integration between agencies.

Beyond technical factors, policy aspects also play a crucial role in strengthening maritime security. That et al. (2023), a country's maritime security policy can influence security perceptions in the Asia-Pacific region, including among ASEAN countries. This means that every policy adopted will have a broad impact on regional security dynamics. This emphasizes that Indonesia's approach to formulating maritime security policies and strategies must consider the region's geopolitical context to remain adaptive to changes in the strategic environment. Therefore, establishing a



maritime security posture is not merely a technical endeavor but also an instrument for building strategic perceptions. For Indonesia, strengthening its maritime security system involves more than just technical effectiveness; it is also closely linked to geopolitical strategy and defense diplomacy. Within this framework, the development of a geospatial-based maritime border surveillance system serves not only an operational function but also contributes as part of broader defense diplomacy. Credible maritime surveillance capabilities are crucial for Indonesia to strengthen its position in regional security relations.

An approach that combines technological and policy aspects in the maritime sector, particularly to address illegal activities, can be strengthened through the use of multimodal spatial data and artificial intelligence (AI) to automatically detect anomalies and changes. The integration of geospatial technology, Automatic Identification System (AIS), remote sensing, and remote sensing, supported by the active involvement of various stakeholders, provides a significant opportunity for Indonesia to build a stronger, more adaptive, and data-driven maritime security system. This effort paves the way for significant improvements in maritime surveillance capabilities, both in terms of detection, prediction, and response. With this foundation, this paper is prepared as a contribution to strengthening maritime security through the application of geospatial integration in the Indonesian Archipelagic Sea Lanes (ALKI).

THEORITICAL INSIGHT

Developments in maritime research demonstrate that the integration of digital technology, big data, and artificial intelligence (AI) is increasingly important in supporting security and risk management in the maritime sector. A bibliometric study by Meyers et al. (2021) confirms that data from the Automatic Identification System (AIS) has become the primary basis for global research into maritime analytics, ranging from vessel density mapping to movement anomaly detection, which increasingly utilizes machine learning and AI approaches. Meanwhile, Munim et al. (2020) found that big data and AI research in the maritime industry forms four main clusters: digital transformation, AIS data utilization, energy efficiency, and predictive analytics. This demonstrates that big data and AI not only support the technical aspects of navigation but also drive operational efficiency and sustainability in the maritime industry. On the other hand, Rawson et al. (2022) highlighted the need for a new approach to maritime risk analysis through the application of the Discrete Global Grid System (DGGS), which is capable of integrating various heterogeneous datasets such as ship traffic data, metocean conditions, bathymetry, and maritime infrastructure. This approach allows the application of machine learning algorithms, such as



Random Forest, to predict ship accident risks spatially, resulting in more accurate and useful risk maps for policymakers. Thus, from this research, it can be seen that theories and approaches based on big data, AI, and geospatialization are an important foundation for building a more adaptive, predictive, and integrated maritime security and safety system in the digital era.

METHODOLOGY

The research method used for this analysis involves a comprehensive qualitative approach, including literature review and document analysis. The literature review was conducted by reviewing various academic sources, including scientific journals, books, and research reports relevant to the topic of Maritime Security with Geospatial Integration of the Indonesian Archipelagic Sea Lanes (ALKI). References used include articles from the journal "Journal of Marine Science and Engineering" by Wolsing et al. (2022) regarding AIS anomaly detection on maritime routes, "Transportation Research" by Li et al. (2023) regarding modeling and analysis of ship trajectory predictions based on AIS data based on machine learning and deep learning methods, and "Transportation Research Interdisciplinary Perspectives" by Meyers et al. (2021) regarding a bibliometric study of maritime research involving the Automatic Identification System.

RESULT

Several studies have shown that the use of digital technologies such as the Automatic Identification System (AIS), big data, artificial intelligence (AI), and geospatial analytics has had a significant impact on the development of the maritime sector. International studies demonstrate a consistent trend of increasing research, both in terms of publication volume, research topics, and the development of spatial and predictive analysis methodologies. In general, these research findings can be mapped into three main focuses: the development of AIS and big data research, the integration of geospatial technology in risk analysis, and the application of AI to detect anomalies and illegal activities at sea.

Strengthening the detection of illegal and anomalous activities at sea according to Li et al. (2021) shows that the combination of remote sensing with AIS can improve the accuracy of detecting IUU fishing activities, especially in remote areas that are difficult to monitor. Meanwhile, the study Anomaly Detection in Maritime AIS Tracks confirms that machine learning and deep learning algorithms are effective in detecting abnormal behavior, including AIS signal manipulation (spoofing) and ship route deviations. Both studies emphasize that the integration of AIS with AI technology and satellite imagery not only expands surveillance coverage but also



strengthens early detection systems that are adaptive and relevant to contemporary maritime threats.

Meyers et al. (2021) conducted a bibliometric study of 817 publications, showing that AIS-based research has experienced significant growth since the mid-2000s, with China, the United States, and European countries becoming the dominant actors. These findings demonstrate that AIS has evolved from a mere navigational communication tool to a strategic database supporting security, logistics efficiency, and global maritime policy. Similarly, Munim et al. (2020) found that the use of big data and AI in the maritime industry is concentrated in four main clusters: digital transformation, AIS applications, energy efficiency, and predictive analytics. These two studies emphasize that AIS and big data are the main foundations for modernizing the maritime sector and reflect the increasing need for digital solutions to address the complexity of maritime traffic.

Other research findings also highlight methodological innovations, as evident in Rawson et al. (2022) study, which proposed the use of the Discrete Global Grid System (DGGS) to integrate AIS, metocean, bathymetric, and maritime infrastructure data within a spatial analytics framework. The result is a high-resolution ship accident risk map that can support maritime incident mitigation. This approach demonstrates that integrating heterogeneous spatial data can produce more comprehensive and precise information, while expanding the function of AIS beyond simply recording traffic to become part of a predictive analytics system. Thus, the development of geospatial-based methodologies strengthens the relevance of digital technology in supporting maritime security and safety policies.

DISCUSSION

The development of digital technology during the industrial revolution has brought significant transformations to the maritime sector, particularly through the use of Automatic Identification Systems (AIS), big data, artificial intelligence (AI), and geospatial technology. Initially designed to improve navigational safety, AIS systems have evolved into strategic data sources to support Maritime Domain Awareness (MDA), predictive analytics, and the development of autonomous navigation. As maritime traffic volumes and maritime threats become more dense, research on the integration of AIS data with digital technology is gaining global attention. This is reflected in the increase in scientific publications that utilize big data, AI, remote sensing, and spatial frameworks such as the Discrete Global Grid System (DGGS) to address contemporary maritime issues.

Indonesia, as an archipelagic nation strategically located along international shipping



lanes, faces significant challenges in maintaining maritime security, including illegal, unreported, and unregulated fishing (IUU fishing), smuggling, and the threat of infiltration by non-state actors. Therefore, understanding global research trends and leveraging academic findings related to AIS, AI, and big data are crucial steps to strengthening the national maritime security system. This article outlines the findings of several leading international studies on the use of AIS data, big data, AI, and geospatial technology, and discusses their implications for developing a more adaptive, integrative, and data-driven maritime security system.

Maritime geospatial technology through Artificial Intelligence is a key instrument in driving the modernization of the maritime industry. The identification of four key clusters in digital transformation: AIS applications, energy efficiency, and predictive analytics demonstrates that the use of digital technology is not only oriented towards the technical aspects of navigation, but also towards operational efficiency, environmental sustainability, and supply chain optimization. For an archipelagic nation like Indonesia, these findings are relevant because they can form the basis for national maritime digital transformation, particularly in logistics management, increasing energy efficiency, and addressing global challenges such as climate change and increasingly competitive international trade.

According to Li et al. (2021), remote sensing further reinforces the urgency of technology integration by demonstrating that combining high-resolution satellite imagery with AIS can improve the detection of illegal activity, particularly IUU fishing. This combination enables surveillance of remote maritime areas that have previously been difficult to reach with conventional infrastructure. This aligns with the challenges faced by Indonesia, which has vast seas but limited surveillance capabilities. By utilizing remote sensing and AIS, maritime surveillance can be carried out more effectively and efficiently, while simultaneously narrowing the scope for maritime law violators. Finally, a study on Anomaly Detection in Maritime AIS Tracks demonstrates the significant potential of AI, particularly deep learning, in detecting anomalous vessel movements such as AIS data manipulation (spoofing) and deviant navigation. This is crucial considering that abnormal activity is often associated with non-traditional security threats, ranging from smuggling to infiltration by non-state actors. The integration of AI with AIS not only improves the accuracy of early detection but also lays a crucial foundation for the future development of autonomous navigation.

Overall, a modern maritime security system must combine technical, methodological, and policy dimensions. Digital technologies such as AIS, big data, AI, and remote sensing can open up significant opportunities for building a resilient, adaptive, and predictive security system.



However, successful implementation depends not only on technological innovation but also on policies that support cross-institutional and international collaboration. In the Indonesian context, utilizing these findings can strengthen ALKI surveillance, enhance threat detection capabilities, and support maritime defense diplomacy in the Asia-Pacific region.

CONCLUSION

The use of digital technologies such as AIS, big data, artificial intelligence, remote sensing, and geospatial analytics has brought about significant changes in maritime security and safety management. Global research developments show that these technologies not only support the technical aspects of navigation and operational efficiency, but also play a crucial role in early threat detection, risk mapping, and strengthening Maritime Domain Awareness. The integration of various data sources enables more accurate, predictive, and adaptive analysis of maritime traffic dynamics and potential maritime law violations. For Indonesia, as an archipelagic nation with a strategic position on international shipping lanes, the implementation of a modern technology-based maritime security system is highly relevant to strengthen surveillance, enhance response to threats, and maintain regional stability and national sovereignty.

FUTURE DIRECTIONS

Strengthening Indonesia's maritime security system, particularly in the Indonesian Archipelagic Sea Lanes (ALKI), requires the integration of digital technologies, including the use of AIS, big data, artificial intelligence, remote sensing, and geospatial analytics, to ensure real-time, accurate, and adaptive maritime surveillance in response to dynamic threats. Approaches such as the Discrete Global Grid System (DGGS) can be implemented to combine diverse data sources, generating precise risk maps as a basis for strategic decision-making. Furthermore, the combination of AIS and satellite imagery needs to be expanded to close surveillance gaps in remote maritime areas while simultaneously increasing the effectiveness of detecting illegal activities such as IUU fishing, smuggling, and infiltration by non-state actors. The implementation of machine learning and deep learning algorithms also needs to be developed to detect anomalous vessel movements, data manipulation, and suspicious navigation patterns, ultimately strengthening early detection and rapid response systems. However, the success of this strategy depends not only on technological readiness but also on policies that encourage inter-agency data integration, strengthening human resource capacity, and international collaboration to establish common standards in maritime security.



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