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Editorial

Maritime Security and Risk Assessments

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Abstract: The main topics of the presented papers focus on various aspects of maritime operations and security, including anomaly detection in maritime traffic, collision risk assessment, and the use of Automatic Identification System (AIS) data for enhancing maritime safety and surveillance. These papers cover a wide range of subjects within the maritime domain, such as trajectory clustering, kinematic behaviour analysis, Bayesian networks for risk assessment, resilience analysis of shipping networks, and the development of novel methods for detecting abnormal maritime behaviour. The emphasis is on using data-driven approaches, statistical methodologies, and advanced technologies to improve maritime operations and security.

1. Introduction

Shipping is relatively safe and clean, but maintaining this state of affairs is an intensive and expensive business. As technology advances, operating systems on board commercial vessels are becoming more specialised and complex. The development of automated systems to monitor, analyse, and regulate the various operations or services on board relies on computer applications to centralise and optimise decision making. Such systems are highly vulnerable to cyber attacks. In addition, crew reductions and the general trend towards reducing the number of people on board ships are being implemented on a large scale. In some ports, pilotage services are already being provided remotely. The first LNG ship recently sailed autonomously across the ocean, and several maritime universities are already preparing for the new era of seafarers who will remotely monitor and control ships' navigation and propulsion elements. There are many technical and regulatory challenges, such as the robustness and resilience of autonomous navigation technology, on-board systems, communications, land-based traffic management, piracy, and cyber security; in addition, ports are a key element of the maritime transport chain and are also vulnerable to cyber attacks. In addition, larger ships and increased port traffic can lead to increased risks at the ship level.

This Special Issue on "Maritime Security and Risk Assessments" presents a comprehensive exploration of key maritime operations and safety issues. Its collection of 16 manuscripts covers various topics, including vessel traffic analysis, collision risk assessment, and vessel traffic service (VTS) operations. Researchers have looked at predicting vessel traffic density using advanced time-series models, mapping fishing activity using Automatic Identification System (AIS) data and developing frameworks for anomaly detection and route prediction based on vessel patterns. The importance of AIS in enhancing maritime security is a recurring theme throughout the manuscripts, focusing on technological advances and efforts to reduce piracy. In addition, the papers highlight the metrics and provider-based results for satellite-based AIS services, emphasising the importance of completeness and temporal resolution in maritime surveillance. The real-time identification of anchorage collision risks based on AIS data is a critical aspect discussed in several manuscripts, highlighting the need for advanced risk assessment models in complex

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maritime environments. Overall, this collection of manuscripts provides valuable insights into ensuring navigational safety, mitigating maritime risks, and improving maritime governance through innovative technologies and analytical approaches.

2. Contemporary Challenges in Maritime Safety and Security

In the dynamic landscape of maritime security and risk assessments, sophisticated tools, devices, and sensors are pivotal in fortifying safety measures and bolstering surveillance capabilities [1]. The integration of the Automatic Identification System (AIS) for real-time vessel tracking and collision avoidance as well as radar systems, which are adept at detecting vessels and assessing risks in diverse weather conditions, forms a robust foundation for maritime safety protocols. Complementing these technologies, Closed-Circuit Television (CCTV) cameras offer visual surveillance of critical maritime infrastructure, while cameras, including near-shore and satellite imaging, provide invaluable insights into vessel behaviours and anomaly detection [2]. Leveraging remote sensing technologies, such as satellite imagery, enhances the monitoring of maritime traffic and facilitates the identification of illicit activities. Vessel Monitoring Systems (VMSs) ensure regulatory compliance among fishing vessels [3], while Global Navigation Satellite System (GNSS) technology enables precise navigation and efficient route planning. The seamless communication facilitated by VHF radios fosters effective coordination between vessels and maritime authorities, optimising operational efficiency in busy waterways. By synergising these tools, researchers and stakeholders in the maritime domain can elevate their capabilities in monitoring, analysing, and responding to maritime incidents, thereby promoting a safer and more secure maritime environment even when conventional and autonomous ships meet [4].

The security issue is still relevant in maritime piracy [5], a problem recently modelled by Contribution 12, who developed a Bayesian network model to assess the risk of pirate hijacking. By incorporating various factors, such as geographic location, vessel characteristics, security measures and historical piracy data, the prediction of the likelihood and impact of hijacking incidents with surveillance data, including AIS information, is of great importance in improving the model's accuracy. It demonstrates the effectiveness of Bayesian networks in maritime security and provides valuable insights for improving preventive measures and decision-making processes to ensure safer maritime operations; also, it explores strategies for predicting and preventing maritime piracy. Ref. [6] propose several policy recommendations to enhance maritime security, including the implementation of international cooperation frameworks, the deployment of naval patrols in high-risk areas, and the adoption of the best management practices by shipping companies.

Recently, however, we have been confronted with entirely new threats for which we do not yet have the right answers. These include attacks on ships by militant groups [7] and severe jamming of GNSS receivers, which can have a significant impact on ship safety. The security threat posed by Houthi attacks on ships in the Red Sea has been the subject of academic and political debates. These attacks, which began in earnest in late 2023, have significantly disrupted global shipping lanes and caused economic ripples worldwide. The Houthis have targeted various commercial vessels, prompting major shipping companies to reroute their voyages around the Cape of Good Hope, significantly increasing transit times and costs. This can add up to two weeks to a shipment's journey. Figure 1 shows the diversion of ships around the Cape of Good Hope [8].

The attacks have led to increased insurance premiums and operating costs for shipping companies, with notable disruptions in the supply chain. Some ships have experienced extreme delays, affecting the trade between Asia and Europe as well as increasing shipping costs. The international community, including the United States and NATO allies, has responded with military operations and sanctions to mitigate the threat, but the situation remains tense and unresolved. Traffic through the Suez Canal has fallen by 70% in tonnage. These developments highlight the urgent need for a coordinated international effort to secure vital sea lanes and address the wider implications of such disruptions for global trade and economic stability. Furthermore, interference with GNSS systems is also very threatening, either through jamming or, even worse, spoofing [9]. Recently, positioning systems have been jammed in the Black Sea, the Eastern Mediterranean, and the Suez Canal. Pilots already face the challenge of navigating large ships through a narrow and winding canal [10] and berthing MGX class container vessels to the quay, hopefully not contacting the STS crane [11]. The situation becomes even more complex when a large ship, exposed to strong winds, heavily drifts in a narrow canal. To make matters worse, the crew suddenly loses confidence in the positioning system (failure of GNSS incidentally also affects radar stabilisation). The extent of such spoofing and jamming was also discussed at the last CHENS meeting (Chiefs of European Navies), where, among others, Androjna and Perkovič [12] presented some recent examples of spoofing, such as the sudden jump of a ship in Suez, which is shown in the Figure 2.

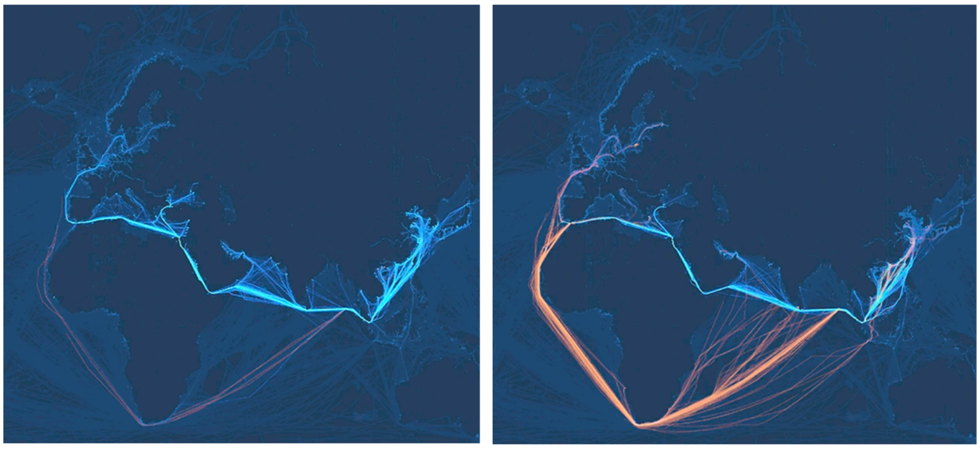

Figure 1. The increase in trade voyages between China and Europe via the Cape of Good Hope has been mapped using monthly AIS data (October 2023 vs. January 2024) [8].

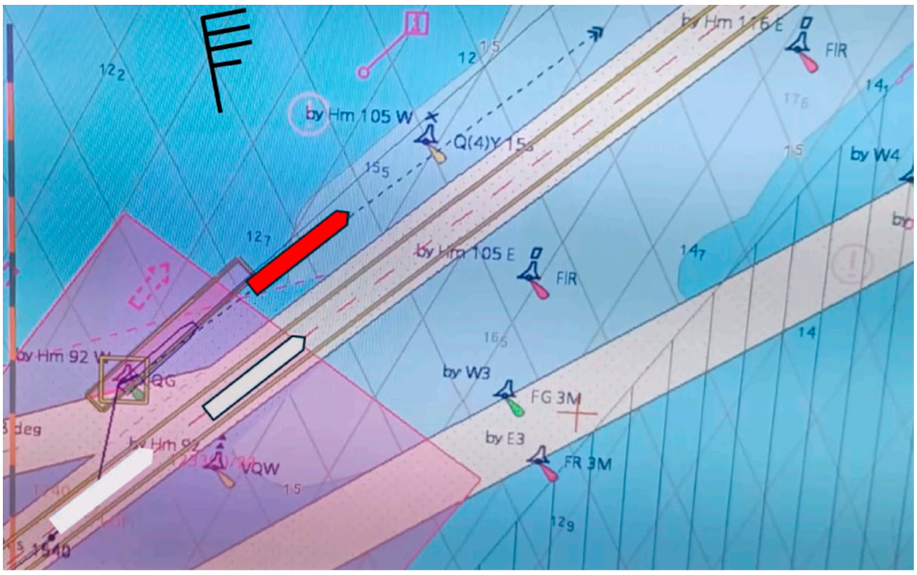

Figure 2. When you lose confidence in your vessel's position at a critical moment, as happened with the box ship Maria Elena recently at the exit of the Suez Canal in strong winds (35 knots), the consequences can be dire. This loss of confidence can stem from purely technical reasons. While major position shifts clearly indicate spoofing, even small deviations, which are harder to detect, can be extremely dangerous [12].

Such deliberate shifts or jumps in position due to intentional acts or technical failures pose a challenge to the ship's crew, marine pilots, and surveillance/control centres that monitor shipping traffic. Intelligent ship control is increasingly available, but it must reconstruct the trajectory correctly under uncertain conditions [13] and, when needed (in case of collision avoidance), predict vessel prediction or turning [14], which is extremely challenging when data are malicious. It should be noted that four levels of ship autonomy are currently defined, the first three of which require direct human involvement. Full autonomy also requires more accurate ship models, but even the most accurate model's prediction of a ship's behaviour will still deviate from reality. This is particularly important when it comes to enabling autonomous docking, where the positioning, communication and control system must be flawless, and a model must be included to represent the work of the ship's pilot [15].

3. Published Articles

This Special Issue encapsulates a diverse array of cutting-edge research endeavours to enhance navigational safety, mitigate risks, and bolster security measures in the maritime domain. The 16 manuscripts within it delve into pivotal themes such as collision risk assessment, anomaly detection, vessel traffic service (VTS) operation optimization, and utilising Automatic Identification System (AIS) data for maritime surveillance. Drawing on a rich tapestry of methodologies and tools, the researchers explore the complexities of maritime traffic patterns, the identification of abnormal behaviours, and the development of advanced risk assessment models.

By integrating microscopic and macroscopic factors, the scholars aim to comprehensively understand the collision risks between ships and in specific water areas. Furthermore, the significance of satellite-based AIS services underscores the importance of data completeness and temporal resolution in maritime surveillance. The manuscripts also shed light on the potential of emerging technologies, such as artificial intelligence and machine learning, to revolutionise anomaly detection and route prediction. Moreover, optimising VTS operations is identified as a critical area for future research, emphasising the need for advanced decision support systems to manage maritime traffic effectively. Researchers aim to pave the way for a safer and more secure maritime environment by addressing governance challenges and exploring innovative solutions. Through a multidisciplinary approach and a synthesis of diverse methodologies, these manuscripts collectively contribute to advancing maritime security and risk assessments, offering valuable insights and paving the way for future research endeavours in this dynamic and critical field.

In particular, the authors delve into utilising Bayesian networks and Petri nets to address maritime piracy confrontations, emphasising the importance of AIS and surveillance cameras for data collection. Another investigation focuses on the risk assessment of pirate hijacking, employing Bayesian networks and the N-K model, relying on surveillance cameras and risk assessment tools for a comprehensive analysis. Furthermore, the dynamic irregular grid approach for navigation safety evaluation, utilising GPS systems and navigation tools to enhance maritime operations, is explored. Additionally, hierarchical analysis, fault trees, and Bayesian networks are employed to conduct a ship collision causation analysis, highlighting the significance of vessel tracking systems and collision detection tools in understanding collision scenarios. Developing a ship collision risk evaluation model and a multi-ship encounter risk assessment model underscores the importance of radar systems and collision risk assessment tools in enhancing maritime safety protocols. Another study adopts a Bayesian network approach for the resilience analysis of maritime accidents, emphasising the role of data logging devices and sensor networks in assessing accident scenarios. The application of movement extraction, data aggregation, data analysis, computer vision, and deep learning techniques showcases the significance of AIS, surveillance drones, and image processing tools in maritime piracy analysis. Additionally, the utilisation of AHP and TOPSIS for multi-criteria decision making highlights the importance of decision support systems and data analytics tools in enhancing decision processes.

Through these comprehensive studies, this Special Issue significantly advances our understanding and implementation of maritime security and risk assessment strategies. By leveraging the latest advancements in technology, data analytics, and risk assessment frameworks, researchers are poised to shape a safer and more secure maritime environment, setting the stage for continued innovation and progress in this critical field.

Author Contributions

Liu et al. (Contribution 1) investigated and addressed the increasing complexity of vessel traffic in waterways due to increasing vessel traffic, varying environmental conditions, and the need for effective collision risk prediction and management strategies. The research problem focuses on the need for advanced tools and methods to assess and manage the risks associated with complex vessel traffic situations to improve safety and efficiency on busy waterways. The researchers proposed a model based on a molecular dynamics approach to assess the complexity of vessel traffic from both temporal and spatial perspectives, considering vessel motion parameters and spatial distribution characteristics. The proposed model was shown to accurately identify and quantify vessel traffic in a waterway using real AIS and simulated data. By objectively assessing the complexity of vessel traffic, the model can help maritime surveillance operators to monitor and organise vessel traffic more effectively, especially in complex traffic scenarios. Prospects for future research in modelling vessel traffic complexity include extending model parameters, adapting coefficients to different water environments, improving validation with real data, improving risk assessment methods, and integrating different surveillance technologies to increase safety and efficiency in managing complex vessel traffic scenarios.

Paper 2 addresses the problem or challenge of decentralised documentation of maritime incidents and presents a novel approach to improve incident investigation in the maritime industry. The study focuses on developing a system that allows multiple entities to contribute and document data in a trusted, decentralised, and tamper-proof manner to support conflict resolution. Existing approaches focus primarily on data from one's own vessel, neglecting valuable information from external sources that could contribute to a better understanding of critical traffic situations. The process of aggregating data from different actors equipped with sensors, which is then signed by a time-stamping authority to ensure data integrity, is proposed. The results highlight the importance of collecting data from multiple sources to fully understand critical traffic situations, especially when traditional investigation methods are limited. By proposing a method that guarantees non-repudiation of recordings and ensures data authenticity, the research addresses the trust issues that can arise between stakeholders during incident analysis. The conclusion highlights the importance of establishing a decentralised and trustworthy documentation system for maritime incidents, emphasising the need for a reliable database that includes contextual information beyond ship-related data.

The research by Ma et al. (Contribution 3) examines the identification and analysis of human errors in maritime safety operations to improve safety measures on board ships. Among the key factors influencing human error in maritime safety identified in the study are the error-producing conditions (EPCs) present in specific tasks on board ships. These EPCs are critical in determining the likelihood of human error in maritime operations. Factors such as inadequate training, lack of teamwork, inadequate supervision, poor communication, and lack of safety awareness are significant contributors to maritime safety errors. The study uses a novel hybrid approach that combines the SOHRA model, the entropy weighting method, and the TOPSIS model to calculate the probability of human error. By incorporating these models, the research aims to minimise the subjectivity of expert judgements and improve the accuracy of human error assessments. The methodology involves applying the proposed approach to a case study of cargo loading operations on a container ship, involving tasks that pose risks to crew members, shore-side workers, cargo, equipment, port facilities, and the environment. Through expert judgement and calculations based on the hybrid approach, the study identifies specific error-prone tasks and associated mitigation measures. The results show significant differences between the scenarios, with one scenario showing better results regarding the likelihood of human error. The study concludes that while it may be impossible to prevent all human error, it can be minimised through effective analysis and mitigation strategies.

Paper 4 presents a study on route evaluation and similarity measurement of container shipping fleets between the ports of two shipping lines. The study used Automatic Identification System (AIS) data to evaluate route characteristics for container vessels of a single fleet calling at the ports of Savannah and Charleston on the East Coast of the US. The methodology included AIS data pre-processing, route generation, and similarity measurement using Discrete Fréchet Distance (DFD). The research focused on assessing route length, duration, speed, and similarity between different trips, highlighting these parameters' statistical distributions and skewness. The results showed moderately positive correlations for trip length, negative correlations for duration, and highly positively skewed speed distributions. The study found that routes of the same vessels showed the highest similarity. In contrast, routes of different vessels showed greater dissimilarity, with DFD providing a valuable measure for route interpretation. The authors emphasized the importance of route analysis for fleet management, safety considerations, and decision making in the maritime industry. There is potential for future research to extend the analysis to include longer time periods, additional ports, and alternative measures of similarity to improve the reproducibility and applicability of the methodology for wider maritime studies and operational improvements.

The selection of appropriate anchorages is essential to ensure the safety of ships, crew, and passengers during navigation. By selecting appropriate anchorages, the risks of collision, impact, and other hazards can be minimised, with the welfare of all parties involved being the primary consideration. In addition, optimum nautical anchorages contribute to the efficient use of maritime space by providing ample room for ships to manoeuvre, ensuring smooth access for arriving and departing ships. Beyond safety and operational considerations, strategically selecting anchorages can also enhance the attractiveness of coastal areas for nautical tourism, attracting visitors and supporting local economic activities. In addition, carefully siting anchorages plays a crucial role in environmental protection by preventing damage to marine and underwater ecosystems. By carefully considering various criteria and applying multi-criteria decision analysis methods, stakeholders can make informed decisions that balance safety, economic viability, environmental sustainability, and user expectations, ultimately establishing well-planned and effective nautical anchorages. A case study of Split-Dalmatia County is presented in paper 5, which examines the optimisation of mooring locations using multi-criteria decision-making (MCDM) methods, specifically the Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The research methodology gathered users' opinions through a questionnaire to determine the most important criteria for nautical anchorages, focusing on safety. Based on the weighted criteria, the study identified 15 optimal locations out of 86 possible variants.

With China importing a significant amount of bauxite from Guinea and Australia, the maritime logistics involved in this process face challenges such as long distances, complex marine environments, and the unique property of bauxite to fluidise. To ensure the stable and continuous import of bauxite and the development of China's aluminium industry, assessing and mitigating the risks associated with bauxite shipping logistics is crucial. Paper 6 discusses the importance of risk assessment in maritime logistics and introduces new parameters and methods to effectively prioritise and analyse risks. Traditional methods such as Failure Mode, Effects, and Criticality Analysis are commonly used in risk assessment, but they have limitations in dealing with the complexity and uncertainty of maritime logistics risks. Therefore, this paper aimed to introduce an improved risk assessment model that combines FMECA, fuzzy Bayesian networks, and evidence reasoning to provide a more accurate and comprehensive assessment of risks in bauxite maritime logistics. A risk parameter characterisation system was proposed to introduce sub-parameters to measure the severity after risk occurrence in maritime logistics. To capture the relationships between the antecedent attributes (input parameters) and the criticality levels (output) representing the severity of consequences in the bauxite maritime logistics system, 125 fuzzy rules were created. Finally, a sensitivity analysis was performed to ensure that the model responded appropriately to variations in the input parameters and maintained consistency in the risk assessment results.

Today, ships rely heavily on the availability of GNSS for accurate positioning, navigation, and timing (PNT). However, civil GNSS currently lacks sufficient security measures, and even cryptographically authenticated GNSS signals have recently been shown to remain vulnerable to spoofing attacks; spoofing attackers can replay authentic GPS signals in near real time to break receiver lock. Combining secured GNSS information with nautical data and other positioning techniques may be able to prevent position spoofing. The paper by Spravel et al. (Contribution 7) proposes MAMA, a software-based GPS spoofing detection framework based on anomaly detection. Unlike other approaches, it is software-based, relies solely on network traffic monitoring, and can be retrofitted. The authors generated a comprehensive tagged dataset using a maritime simulator based on real-world data. It includes several legitimate and spoofed samples and was used to evaluate their approach, and it is also available to others for benchmarking. In their future work, the authors plan to extend their evaluation and explore the potential of an intelligent ensemble of individual detection methods. They aim to improve detection capabilities and address deficiencies in detecting GNSS spoofing attacks in maritime systems.

Future maritime autonomous surface ships (MASSs) will rely heavily on machine learning algorithms and computer vision systems to navigate, detect, and avoid obstacles. However, the maritime industry faces new AI-related threats, such as adversarial attacks. In their paper, C. Lee and S. Lee (Paper 8) investigated the vulnerability of object detection and classification algorithms. They highlighted the importance of considering the security threats of deep neural network (DNN)-based object classification algorithms to various attack methods, such as FGSM, I-FGSM, MI-FGSM, and PGD. In particular, they investigated a very popular approach, the "you only look once version 5" (YOLOv5) algorithm, by training it on the Singapore Maritime Dataset (SMD-Plus) and then challenging it with adversarial attacks based on perturbed images generated by six pre-trained DNN algorithms and four adversarial attack methods. The results show that all algorithms and adversarial attack methods significantly reduce accuracy and pose significant security threats to AI systems during training. The study also acknowledges limitations in the experimental design. It highlights the need for further research into the vulnerability of AI systems to adversarial attacks and the development of mitigation strategies to enhance cybersecurity in the maritime industry.

Liu et al. elaborate a safety analysis method (paper 9) based on a network model of ship collisions, which relates causal factors with their inter-relationships to quantify the importance of each factor and thus identify key causal factors of ship collisions. The study proposed a successive safety evolution process based on the network model, where the safety protection strength of each causal factor was quantified, and a safety evolution process was initiated to control the proliferation of ship collisions. Based on the study of 300 ship collisions in Chinese waters, they extracted 98 causal factors. Unlike the existing studies that directly use the number of accidents as an important indicator of a particular causal factor, they propose to examine network efficiency to measure the importance of accident causation. Using this approach, their results are consistent with previous studies that have identified, for example, poor lookout as a major cause of accidents. However, the network analysis also identified those factors for which the probability of an accident is lower than for others, while at the same time having a higher degree of influence on the incidence of ship collision accidents.

A comprehensive review by Stache et al. (Contribution 10) provides valuable insights into the advances and challenges in maritime anomaly detection to improve the safety and efficiency of vessel traffic services. The review highlights various publications from 2017 to

2022, focusing on AIS-based anomaly detection techniques, statistical analysis, clustering, and neural networks. It highlights the importance of descriptive statistics and compares the results of different anomaly detection techniques in specific scenarios. The Automatic Identification System was the primary data source for anomaly detection due to its ubiquity, standardised structure, and coverage of relevant maritime traffic information. In terms of detection techniques combined with anomaly types, the anomaly types of route deviation and kinematic deviation are covered by the commonly used techniques of descriptive statistics, clustering, or NN-based classification. It is worth mentioning that NN-based detection in ship behaviour has shown promising results. However, a key concern is the lack of explainability in the decision-making process of NN-based systems, which may hinder trust and acceptance by VTS operators. The authors also discuss future work required to improve the utility of decision support tools (DSTs) in daily VTS operations, including integrating VHF data, generating annotated training data, and implementing realistic operator test beds.

The authors of paper 11 focus on improving Maritime Domain Awareness (MDA) in Brazil through a data-driven framework (CV-MDA) using computer vision technology. The research addresses the challenges of monitoring vessel activity in territorial waters and highlights the importance of accurate and reliable data for effective surveillance. By integrating data sources such as Automatic Identification Systems and Long-Range Identification and Tracking, the framework aims to consolidate vessel movement data to improve MDA. The proposed CV-MDA framework consists of three layers—Data Acquisition, Integration, and Detection/Classification—using a fine-tuned transfer learning approach for vessel detection. The study highlights the importance of data integration in increasing awareness. In addition, the research contributes to the advancement of maritime surveillance by addressing the challenges of monitoring vessel activity and enhancing the capabilities of surveillance systems. By leveraging computer vision technology and integrating multiple data sources, the framework improves situational awareness, supports effective decision making, and strengthens maritime surveillance worldwide to address security risks and illegal activities in territorial waters.

Through a systematic risk analysis approach, paper 12 provides valuable insights into the complex dynamics of pirate attacks along the Maritime Silk Road to enhance maritime security in the region. The paper addresses the critical issue of maritime piracy and its impact on shipping. The study identifies key risk factors that affect the vulnerability of ships to pirate attacks, highlighting the interaction of hazard, mitigation capacity, and vulnerability/exposure as crucial components in assessing the risk of attacks. By applying dynamic Bayesian network analysis, the research provides a comprehensive understanding of the pirate attack process, enabling stakeholders to better understand and mitigate the associated risks, highlighting the impact of natural and man-made hazards. DBN extends traditional Bayesian networks by incorporating temporal dependencies, enabling dynamic behaviour modelling over time. This enables the analysis of how different factors such as waves, visibility, number of pirates, weapons, political and economic situations, and naval support interact and evolve to influence the risk of pirate attacks. By considering these dynamic variables, DBN enables a more scientific, intuitive, and accurate assessment of the process risk of pirate attacks on ships. The study highlights the importance of crew training, anti-piracy drills, self-defence equipment, and surveillance intensity to improve ships' resilience against pirate threats.

In paper 14, Liu et al. present an analytical model for the real-time identification of anchorage collision risk based on AIS data to address the increasing challenges of maritime safety in congested port environments. The model incorporates three key aspects: microscopic collision risk, macroscopic collision risk, and traffic complexity. The microscopic aspect focuses on the relative motion between vessels to assess the collision risk of individual vessels. In contrast, the macroscopic aspect evaluates the characteristics of the anchorage area, considering safe navigable waters within variable boundaries. The model was developed to consider traffic complexity by analysing the spatial compactness of vessels in the anchorage. By integrating these aspects, the model provides a comprehensive approach to assessing collision risks in anchorage areas, enabling stakeholders to make informed decisions and implement targeted safety measures. The model's real-time monitoring capabilities using AIS data enable the continuous risk assessment and proactive intervention to improve safety and operational efficiency in ports worldwide. Experimental case studies have validated the effectiveness of the model in accurately identifying collision risks. The model also considers vessel traffic density and spatial complexity for a more accurate risk assessment.

Brcko and Luin (paper 14) present a novel decision support system that uses fuzzy logic to improve situational awareness and assist the navigator in collision avoidance in multi-ship encounters. The study begins by highlighting the conventional approach of using a simple radar circle model with a radius of up to one nautical mile for ship-safe areas. The methodology section outlines the research process, including a literature review focusing on emerging collision avoidance decision models, the development of algorithms to calculate collision risk and avoidance manoeuvres, the use of fuzzy logic for decision making, and the conduct of Monte Carlo simulations to evaluate the performance of the proposed model. The integration of the International Regulations for the Prevention of Collisions at Sea (COLREGs) with artificial intelligence techniques forms the model's backbone. Simulation tests show the effectiveness of the fuzzy-based decision model in two-vessel scenarios, although it has limitations in complex multi-vessel situations. Decision support systems are an important step towards integrating autonomous ships, as the management of these ships in the transition phase will mainly depend on the experience and competence of the seafarers. In addition, the paper highlights relevant issues for further study, particularly concerning revising the COLREGs on collision avoidance at sea, especially in multi-ship situations. A particularly important area in this respect is the study of the feasibility of determining the right of way from a ship's perspective. Spatially based route planning is a promising solution to these challenges and should be the subject of thorough investigation and research.

Vessel traffic service providers need efficient, context-sensitive tools to detect anomalous vessel behaviour. Current approaches, such as deep neural network models for detecting anomalous vessel behaviour, lack interpretability. Olesen et al. present a novel method for detecting anomalous vessel trajectories based on two-stage clustering that considers providing contextual decision support to VTS operators (paper 15). Their basic idea is to relate predictions to behavioural clusters and consider kinematic similarity measures (i.e., changes in speed and course) to assist the operator in accepting or rejecting the algorithm's prediction. For the evaluation, they created and published two large hand-annotated AIS traffic datasets containing more than 30,000 trajectories from 11 vessel types and marked anomalies covering a full day, including a collision accident, search and rescue activity, and anomalous commercial traffic. The detection performance of their proposed method is lower than that reported for using variational recurrent neural networks (VRNNs). However, it is much faster to compute and provides contextual decision support.

Another article (Contribution 16) examines the landscape of Global Navigation Satellite System (GNSS) spoofing. It is well known that Automatic Identification System (AIS) spoofing can be used for electronic warfare to conceal military activities in sensitive maritime areas. However, recent events suggest a similar interest in spoofing AIS signals for commercial purposes. The shipping industry is experiencing unprecedented fraudulent practices by tanker operators seeking to evade sanctions. This article addresses the issue of AIS manipulation, particularly in the context of the illegal oil trade, which is fuelled by the ongoing war between Ukraine and the Russian Federation. It highlights a major gap in the nexus between law, economics, science, and policy. Repeated cases of discrepancies between AIS position reports and satellite radar images have led to the detection and documentation of AIS position falsification by tankers carrying Russian crude oil in closed ship-to-ship (STS) transfers and by unofficially registered tankers ("ghost ships"), with direct implications for maritime safety. The risk posed by STS transfers depends on the boundaries of the transfer area, environmental restrictions, weather conditions, sea state, traffic density, good anchorage conditions, ship characteristics, and compliance with international and local regulations. These false ship positions underline the need for effective tools and strategies to ensure the reliability and robustness of AIS.

4. Outlook Research

The outlook for maritime safety and risk assessment research shows a promising trajectory with several key focus areas and associated challenges. Critical research directions are improving collision risk assessment models by integrating microscopic and macroscopic factors, refining anomaly detection techniques to identify abnormal vessel behaviour, and optimising vessel traffic service (VTS) operations through advanced technologies. In addition, overcoming challenges related to data completeness and temporal resolution in satellite-based AIS services, exploring the potential of emerging technologies such as artificial intelligence and machine learning, and addressing governance issues such as piracy prevention and environmental protection are essential to advancing maritime safety and security. In ref. [16], several possibilities for the future development of maritime safety are identified. In particular, further developments in automation and remote control with autonomous ships and unmanned navigation systems will reduce operating costs and increase safety. Integrating artificial intelligence and machine learning will create smarter navigation systems for better hazard prediction and optimised shipping routes. Cybersecurity measures must be strengthened to protect digital technologies and communication systems from cyberattacks. Integrated maritime traffic management systems combining satellite data, AIS, and radar will improve traffic management and reduce collision risks. Education and training programs must be interdisciplinary in their focus on technological advances and environmental issues. Finally, international cooperation is essential for harmonising global regulations and standards to ensure shipping safety worldwide.

To achieve these goals, researchers can use data analysis, machine learning, geospatial analysis, simulation and modelling, network analysis, risk assessment frameworks, and remote sensing technologies to enhance their studies and develop innovative solutions.

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