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Merging the Application of Artificial Intelligence Technology in Maritime Industry: A Systematic Literature Review

Mohd Shafeeq Mohd Tahir[1,*], Ramlee Mustapha[1], Mohd Ekram Al Hafis Hashim[2], Norsalwati Mohd Razalli[3], Arthit Kleebrung[4]

[1] Faculty of Technical and Vocational, Sultan Idris Education University, 35900 Tanjung Malim, Perak, Malaysia
[2] Faculty of Art, Sustainability and Creative Industry, Sultan Idris Education University, 35900 Tanjung Malim, Perak, Malaysia
[3] Manjung Community College, 32040 Seri Manjung, Perak, Malaysia
[4] Faculty of Information Technology Development, Khon Kaen Vocational College, Mueang Khon Kaen District, Khon Kaen 40000, Thailand

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ABSTRACT

This article presents a thorough literature review on the use of technology in artificial intelligence technology within the maritime industry. The aim is to analyse existing research and identify crucial themes, theoretical frameworks, methodologies, and areas of research gaps in this field. Specific keywords related to artificial intelligence and the maritime industry were used to search the Web of Science (WoS) and Scopus databases. A list of the 34 most frequently cited articles was compiled and analysed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a systematic and rigorous approach to selecting relevant manuscripts. The analysis revealed three key themes: (1) Role of Artificial Intelligence technology in the maritime industry, (2) challenges in adapting Artificial Intelligence technology in the maritime industry and (3) digitalisation and smart shipyards. Additionally, navigational safety and environmental impact were identified as important considerations in this field. Integrating artificial intelligence into maritime organisations able to develop immersive and impactful syllabus that simulate advanced technology. This allows maritime practitioners to develop related skills and better understand advanced technology. Furthermore, this integration fosters growth and success in the maritime industry, preparing for future development.

1. Introduction

The maritime industry is currently undergoing a profound technological revolution, characterised by the integration of innovations such as autonomous vessels, Artificial Intelligence (AI), data-driven decision-making, and intelligent shipyards. This compilation of articles examines the intricate details of these advancements, shedding light on their transformative influence on the industry's trajectory. Within the context of autonomous maritime operations, a significant paradigm shift is unfolding as vessels adapt to navigate, communicate, and interact in complex

* *Corresponding author.*
E-mail address: mohdshafeeq.6173@gmail.com

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maritime environments. In order a vessel to equipped with AI systems and advanced sensor arrays, the vessel is prepared to redefine conventional concepts of vessel control [11,12]. An innovative approach termed "Autonomous Collision Avoidance" utilises Multi-Agent Deep Reinforcement Learning (MADRL) to simulate integration of collision avoidance awareness among multiple vessels, facilitating informed decisions analogous to human cognition [4]. The maritime domain has become a fertile ground for data-driven insights and decision-making, with articles emphasising the interplay between vessel sensor data and AI perception, judgment, and control [5,16]. Another application of sensor is the use of aerial remote sensing and ground geophysical methods has greatly benefitted researchers in archaeology and related fields, allowing for improved exploration and analysis. Some authors suggested that these techniques can be used to identify ancient crop markings by studying soil erosion. Additionally, advanced data fusion techniques like "archaeo-geophysics" are becoming more complex and efficient in rapidly and non-invasively locating and identifying buried ancient structures [24]. Conversely, AI shapes vessel operation and control, reinforcing the symbiotic relationship between these systems. The potential of Big Data and AI is harnessed to employ predictive analytics for forecasting LNG bunkering demand, optimising fuel consumption, and minimising environmental impact [38]. In the realm of digitalisation and smart shipyards, the shipbuilding process has been revolutionised, guided by technology-driven solutions [14].

Integration of 5G and 6G wireless systems with maritime IoT applications demonstrates the facilitation of data-driven operations through enhanced communication [21]. Furthermore, the convergence of Automatic Identification System (AIS), Geographic Information System (GIS), and e-charts provides a comprehensive analysis of vessel traffic flows and maritime accidents, subsequently enhancing navigational safety and efficiency. The concept of smart shipyards is explored, highlighting the optimisation of vessel design, manufacturing, and operational processes through the synergy of various technologies. Navigational safety and environmental sustainability emerge as paramount concerns throughout the articles, with discussions on mitigating potential cybersecurity threats to autonomous vessels and the maritime industry [19,32]. The integration of advanced technologies introduces associated risks, prompting the development of comprehensive strategies for cyber risk mitigation [1]. A predictive model for vessel trajectory is introduced, leveraging AIS data denoising and predictive modelling to mitigate navigational risks. In conclusion, these articles collectively underscore the dynamic and transformative nature of the maritime industry's technological journey. As the sector embraces autonomy, data-driven insights, and digitalisation, stakeholders must navigate a landscape replete with opportunities and challenges. The insights drawn from this compilation provide invaluable perspectives on the ongoing evolution of the maritime sector and its potential to redefine the future of global maritime operations.

1.1 Advanced Technology in Maritime

The use of advanced technology such as Artificial Intelligence and Machine Learning in the maritime industry is becoming increasingly important. This refers to the application of cutting-edge innovations and digital solutions to enhance maritime operations, safety, efficiency, and environmental sustainability [21]. From vessel navigation to cargo management, safety protocols to environmental compliance, advanced technologies are transforming how vessels are operated and managed [15]. These technologies encompass a range of fields, including automation, data analytics, communication systems, renewable energy integration, and more. Ultimately, the aim is to improve operational efficiency, reduce costs, mitigate risks, and minimise the industry's environmental footprint [21,32,33]. Concrete examples of mentioned technologies are started to be implemented in the maritime industry with great effect. Another approach in other sector is on tracking and executing a GPS tracking system enabled by IoT with the aim of improving the supervision and security of school-age children as they travel to and from school [10]. Simplifying the language used in discussing these advancements would make them more accessible to a wider audience. It is important to highlight the critical role that advanced technology plays in the maritime industry and emphasise the benefits of using the technologies to increase the way of organisation operate their business. Figure 1 shows uses of advanced technologies such as AI in the maritime industry for example maritime search and rescue, harbour and vessel logistics, on-board infotainment, navigation and fleet management and shipborne IoT. The list is not exhaustive to the mentioned but many others where beneficial to the maritime organisation.

Fig. 1. Use case categories in 6G-Maritime Networks [21]

2. Methodology

This section describes how articles on merging the application of Artificial Intelligence technology in maritime industry are retrieved. The researchers used PRISMA, comprising resources such as Scopus as well as Web of Science (WoS) for the systematic review, exclusion as well as eligibility criteria, review process phases such as identification, screening, and eligibility, as well as data analysis and abstraction. Scopus and Web of Science (WoS) are two of the most applied searchable databases for scientific and academic publications [20]. These databases provide a wealth of information on various topics, including research articles, conference proceedings, and scholarly books. An extensive collection of academic literature, researchers can access a vast array of information on the fingertips.

2.1 PRISMA

Researchers conducted a review using the PRISMA methodology, which is commonly used in environmental management. This methodology helped authors to define clear research questions, determine criteria for inclusion and exclusion, and review a large database of scientific literature in a timely manner [13]. By using the PRISMA statement, we were able to search for terms related to the benefits and drawbacks of implementing AI technology in the maritime industry. This allowed the authors to identify areas that require further research. Additionally, this methodology helped to deeply understand the challenges faced by the maritime industry when plan to adopting AI technology.

2.2 Resources

In this study, searching for articles on the implementation of AI technology in the maritime industry was comprehensive and focused on reliability. We used specific keywords and filtered the databases to only display outcomes in the title, abstract, or keywords. This helped this study exclude articles that did not have a substantial connection to the manuscript text. We also worked to minimise the recurrence of articles by carefully searching through the two databases: Scopus and WoS. As a result, we obtained 34 research articles listed in Table 1.

Table 1
Merging the Application of Artificial Intelligence Technology in Maritime Industry, 34 most cited articles in WoS and Scopus databases

Authors	Title	Method	Publication Year
Sharma A.; Undheim P.E.; Nazir S. [23]	Design and Implementation of AI Chatbot for COLREGs Training	To help trainees in the maritime industry learn the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), authors-built a chatbot using the IBM Watson Assistant service. This service enables organisations to create conversational agents that can respond to users' queries and provide them with relevant information. The chatbot has three building blocks: intent, entity, and dialogue. When a user poses a query, the chatbot recognises the intent and responds with appropriate answers or options. With this chatbot, the study aims to make learning the COLREGs more efficient and accessible for trainees in the maritime industry.	2023
Lee C.; Lee S. [14]	Vulnerability of Clean- Label Poisoning Attack for Object Detection in Maritime Autonomous Surface Ships	In this article, the collision avoidance system developer trains an object detection model using a dataset that has been configured without any knowledge. The dataset seems to be normal at first glance, but it has been tampered with by an attacker who collected footage of a vessel that close to other vessel intention to conquered. The attacker is trying to pass off this manipulated dataset as a trustworthy one for the collision avoidance system. Unfortunately, this has resulted in the object detection model misclassifying a boat as a ferry, which could be catastrophic in real-world situations. It is crucial that we remain vigilant and ensure that our datasets are legitimate and free from any sort of manipulation. The authors proposed a hypothetical object detection model with high accuracy training to validate the effects of data poisoning on the collision avoidance system. It is important for developers to be aware of the potential risks of data poisoning attacks and to take steps to prevent and mitigate them.	2023
Yoo J.; Jo Y. [37]	Formulating Cybersecurity Requirements for Autonomous Ships Using the SQUARE Methodology	Maritime communication systems can benefit greatly from the implementation of artificial intelligence and machine learning techniques. These approaches can assist in managing complex integrated systems while also meeting service requirements and energy efficiency goals. It is important to ensure that any datasets used for this purpose is legitimate and free from manipulation, as the misclassification of objects could have catastrophic consequences.	2023

Lee C.-M.; Jang H.-J.; Jung B.-G. [15]	Development of an Automated Spare-Part Management Device for Ship Controlled by Raspberry-Pi Microcomputer Based on Image-Progressing & Transfer-Learning	Apparently, researchers have developed a Raspberry Pi-based embedded application that can identify spare parts applying learning data and algorithm. The experiment was conducted successfully through both a Wi-Fi network and an internet connection in an actual vessel environment, which is quite remarkable. This innovation has the potential to save a lot of time and effort in managing spare parts in the maritime industry.	2023
Kalghatgi U.S. [12]	Creating Value for Reliability Centred Maintenance (RCM) in Ship Machinery Maintenance from BIG Data and Artificial Intelligence	A model has been developed in this study by utilising AI and Big Data technology where there are potentials to revolutionise Reliability Centred Maintenance. By minimising maintenance costs, ensuring the availability of critical machinery and avoiding downtime, this innovation can provide immense benefits to various industries.	2023
Mansoursamaei M.; Moradi M.; Gonzalez-Ramirez R.G.; Lalla-Ruiz E. [19]	Machine Learning for Promoting Environmental Sustainability in Ports	This study applied PRISMA, a standardised method for systematic review reporting. The protocol includes a 27-item checklist and a four-phase flow diagram, which can help to improve consistency across reviews and ensure thorough reporting. A comprehensive methodology that can be used in a variety of disciplines. To execute this protocol, researchers need to define their research questions and identify their search string and source selection.	2023
Daya A.A.; Lazakis I. [8]	Developing an Advanced Reliability Analysis Framework for Marine Systems Operations and Maintenance	The proposed methodology for vessel system reliability combines both quantitative and qualitative reliability analysis approaches. The use of BBN, DFTA, and FMECA to address gaps in the literature seems like a comprehensive and effective approach. Especially since maintenance planning can be challenging due to defects are not identified in OEM's maintenance and troubleshooting manuals. Overall, this methodology seems like a promising way to improve vessel system reliability.	2023
Brandtner A.; Osen O.L. [2]	Assessing Autonomous Ship Navigation Using Bridge Simulators Enhanced by Cycle Consistent Adversarial Networks	This study proposed use of maritime training simulators to evaluate the impact of decision support on performance and vessel's safety including autonomous navigation. The suggestion of using Cycle-GANs to synthesis data before performing classification and object caption is a potentially effective way to address this challenge and enable more accurate and reliable testing.	2023
Ashraf, I; Park, Y; Hur, S; Kim, SW; Alroobaea, R; Bin Zikria, Y; Nosheen, S [1]	A Survey on Cyber Security Threats in IoT-Enabled Maritime Industry	Stakeholders in the maritime industry are concerned on cyber threats and take action to prevent the situation. This study focusses on vulnerabilities in digital transformation, such as using IoT devices and modern security frameworks. The study offers countermeasures to lessen the impact of cyber security breaches and promote safety at sea.	2023
Yi, ZY; Mi, SY; Tong, TQ; Li,	Intelligent Initial Model and	Researchers proposed a conceptual model for designing a civil smart shipbuilding factory, which has been shown to	2023

HM; Lin, Y; Wang, WB; Li, JB [36]	Case Design Analysis of Smart Factory for Shipyard in China	significantly increase production efficiency. The case study found that the modelling of all vessels was completed with a 100% success rate, and pre-outfitting efficiency increased by approximately 95%, while the use of wire cutting robots resulted in a 70% increase in efficiency. These results demonstrate the clear advantages of implementing smart technologies in the maritime industry.	
Kamarudin, N, Nik Hassan N. M. H, Muhamad M.M., Talib, O. Kamarudin H., Abdul Wahab N., Ismail A.S., Borhan H.H, & Idris N. [13]	Unveiling Collaborative Trends in Fuzzy Delphi Method (FDM) Research: A Co-Authorship Bibliometrics Study	Based on this study, the FDM uses fuzzy logic to help experts make complex decisions by dealing with uncertainty. Despite being popular and having many publications. This study looks at how authors work together and how this affects FDM. The authors looked at 766 FDM papers from the Scopus database (1991–2022) using tools like Microsoft Excel, VOSviewer, and Harzing's Publish or Perish. Taiwan and Malaysia are the top contributing countries. FDM helps decision making, building agreement, and planning in areas like making a curriculum and educational policies.	2024
Saafi S.; Vikhrova O.; Fodor G.; Hosek J.; Andreev S. [21]	AI-Aided Integrated Terrestrial and non-terrestrial 6G Solutions for Sustainable Maritime Networking	Integrated system management is a complex task, and this article suggests that AI and machine learning can be achieved to meet requirements needed and optimum energy consumption in different maritime communication scenarios. These advancements enable more efficient diagnostics of torpedo ladle cars and contribute to ensuring the safe and dependable functioning of these systems.	2022
Wang M.; Yu H.; Bell Z.; Chu X. [33]	Constructing an Edu- Metaverse Ecosystem: A New and Innovative Framework	This article elaborated a new theoretical framework that draws on the latest research in instructional design and performance technology related to Metaverse environment. These hubs include a knowledge hub, research and technology hub, a talent and training hub, and an instructional design and performance technology hub. Throughout all four hubs, the framework emphasises the importance of business industry, communication, infrastructure, technology access and equity, user rights, privacy policy and data security as well.	2022
Sorensen J.C.; Lutzen M.; Eriksen S.; Jensen J.B [28]	A Modular Working Vessel Decision Support System for Fuel Consumption Reduction	The authors prioritised energy efficiency to optimise fuel and costs. Despite the availability of cost-effective improvements in the industry, energy-efficient operation is often not given enough importance. The requirements for decision support system can be determined through interviews with workers and observations of vessels environment. This approach will help operator to make informed decisions and operate a vessel in an energy-efficient manner, ultimately reducing costs and promoting sustainability.	2022
HF. Hanafi, MH. Adnan, M. Huda, WA. Mustafa, MM. Ghani, MEA. Hashim, A. Alkhayyat [10]	IoT-Enabled GPS Tracking System for Monitoring the Safety Concerns of School Students	The researchers propose an Internet of Things (IoT) GPS tracking system to enhance child safety during commutes to and from school, targeting children aged 4 to 10. A key feature is the ability to monitor multiple children simultaneously. The primary goal of this IoT solution is to provide parents with peace of mind and a reliable way to respond promptly to any safety concerns during their child's commute.	2024
Ichimura Y.; Dalaklis D.; Kitada M.; Christodoulou A. [11]	Shipping in the Era of Digitalization: Mapping the Future Strategic Plans of	In this study, the researchers applied a concept map based Multi Document Summarisation (MDS) to analyse the digitalisation strategies created by selected maritime players. The study also examined how relevant terminologies are applied and its benefits. This research demonstrates the importance of staying up to date with the latest trends and	2022

	Major Maritime Commercial Actors	innovations in the maritime industry, including digitalisation.	
Zhang, MY; Zhang, D; Fu, SS; Kujala, P; Hirdaris, S [38]	A Predictive Analytics Method for Maritime Traffic Flow Complexity Estimation in Inland Waterways	Researchers utilised a complex algorithm like Lempel- Ziv and TOPSIS to analyse maritime traffic flow. The study based on AIS data from the Yangtze River revealed that high complexity leads to travel time sequences that are not periodic or stochastic, but rather dependent on traffic encounters' evolution patterns.	2022
Veerappa, M; Anneken, M; Burkart, N; Huber, MF [29]	Validation of XAI Explanations for Multivariate Time Series Classification in the Maritime Domain	The authors demonstrated deep learning-based classifiers easier to understand by using explainable artificial intelligence (XAI) techniques. XAI methods can explain predictions and show which features are most important. In the maritime industry, XAI has been used to effectively classify vessel types. For instance, the Lime for Time technique maps time slices, while other techniques generate heatmaps to indicate the relevance of each input variable.	2022
Chou, CC; Wang, CN; Hsu, HP [6]	A Novel Quantitative and Qualitative Model for Forecasting the Navigational Risks of Maritime Autonomous Surface Ships	Quantitative and qualitative model in this study has shown that the risk of mechanical malfunction accidents is highest when operates at sea, while the risk of collision is highest when operate around a port. The data collected from autonomous surface vessels and analysed. All findings could prove useful for policymakers in the future as they work to develop regulations and guidelines for MASS navigation.	2022
Park, S; Huh, JH [22]	Study on PLM and Big Data Collection for the Digital Transformation of the Shipbuilding Industry	The maritime shipbuilding industry in Asia has been able to collect Big Data through the utilisation of Product Lifecycle Management (PLM) data box, which has led to a proposed architecture for Big Data collection. This architecture could potentially contribute to the digital transformation of the industry and assist policymakers in making decisions regarding port facilities and navigational safety regulations for Maritime Autonomous Surface Ships (MASS). The findings from this study on MASS risks, such as the risk of mechanical malfunction accidents and collisions, could also be useful for policymakers in developing regulations and guidelines for MASS navigation.	2022
Veitch, E; Dybvik, H; Steinert, M; Alsos, OA [30]	Collaborative Work with Highly Automated Marine Navigation Systems	Collaborative systems and tools from Computer Support Cooperative Work (CSCW) could be valuable in addressing design challenges in the maritime shipbuilding industry. Studies have indicated that collaborative approaches in diagnostics can lead to better result than relying solely on either physicians or AI. This is consistent with the 'cooperative eye hypothesis,' which proposes that humans evolved to have large sclera to better coordinate with others in cooperative activities. In order to enhance explain ability. XAI approaches could be valuable in the context of the proposed architecture for Big Data collection in the maritime industry, which could contribute to the digital transformation of the sector and inform policymaker.	2022
Yang, CH; Wu, CH; Shao, JC;	AIS-Based Intelligent	The study employed various techniques to predict vessel trajectories, including data denoising and a Bi-LSTM model. The	2022

Wang, YC; Hsieh, CM [35]	Vessel Trajectory Prediction Using Bi-LSTM	collected data was cleaned using trajectory separation, outlier deletion, and data standardisation, and the Bi-LSTM model was utilised to remove noise in AIS trajectory prediction. The prediction efficiency of the algorithm was evaluated by comparing the predicted trajectory to the original trajectory data. Additionally, the study explored the difference in vessel trajectory prediction after data denoising. Overall, the study highlights how combining AI with other approaches can lead to more accurate and efficient results, ultimately benefiting patient outcomes.	
Chou, CC; Wang, CN; Hsu, HP; Ding, JF; Tseng, WJ; Yeh, CY [7]	Integrating AIS, GIS and E-Chart to Analyse the Shipping Traffic and Marine Accidents at the Kaohsiung Port	The authors conducted a study that integrated vessel traffic flow and environmental factors using AIS, GIS, and an e-chart. To combine the three systems, researchers used the Visual Basic programming language to develop an interface. While previous studies have focused on using GIS or AIS GIS to analyse navigational safety or the causes of maritime accidents, this study is unique in using all three tools together.	2022
Xu, P; Zheng, JX; Wang, XY; Wang, SY; Liu, JH; Liu, XY; Xie, GM; Tao, J; Xu, MY [33]	Design and Implementation of Lightweight AUV With Multisensor Aided for Underwater Intervention Tasks	A new kind of intervention AUV has been developed by researchers that is lightweight and utilises data from multiple inertial sensors to navigate autonomously. The AUV design is robust in terms of both software components and mechanical structure, making it an ideal platform for secondary development. The system was tested through surveying and object manipulation experiments in underwater environments, demonstrating its functionality and potential applications in the fields of science and industry. The article addressed target recognition with a colour restoration method for degraded underwater images. The authors also used a strategy called You Only Look Once combined with topological analysis for object detection.	2022
Lee H.-T.; Lee J.-S.; Yang H.; Cho I.-S. [16]	An AIS Data-Driven Approach to Analyse the Pattern of Ship Trajectories in Ports Using the DBSCAN Algorithm	This study aims to develop optimal routes, forecasting, and decision-making technologies related to vessel operation. The authors are collecting data from AIS, chart display, and information systems used by vessels to conduct their research. They are also working on developing vessel manoeuvring guidelines for the port based on AI technology and the analysis of vessel trajectories using the density-based spatial clustering of applications with Noise (DBSCAN) algorithm. The results of this analysis will help them propose new guidelines for the future development of MASS.	2021
R Din, NM Na'in, S Utama, M Hadi, AJQ Almaliki [9]	Innovative Machine Learning Applications in Non-Revenue Water Management: Challenges and Future Solution	The study addresses the global issue of Non-Revenue Water (NRW) and highlights the transformative potential of machine learning (ML) in water management. Authors examined how ML applications, like predictive analytics that able to reduce water losses caused by leaks, theft, and inaccuracies. A significant economic and environmental impacts. The paper explores challenges in implementing ML, such as data quality, model interpretability, and complexity, emphasizing the need for multidisciplinary collaboration to align technology with practical use. Focusing on examples from Europe, China, Japan, South Korea, and specific states in Malaysia underscores that ML can improve the efficiency of NRW management and foster sustainable and resilient water systems.	2024
Pereira M.I.; Claro R.M.;	Advancing Autonomous	Researchers have developed a maritime network between vehicles and port facilities that applied a unique training	2021

Leite P.N.; Pinto A.M. [23]	Surface Vehicles: A 3D Perception System for the Recognition and Assessment of Docking-Based Structures	process with minimal data. The model can recognise different docking structures with over 90% accuracy using low resolution sensors. The result able to demonstrate robustness in varying environmental conditions and could revolutionise maritime industry and application.	
Meyers S.D.; Azevedo L.; Luther M.E. [20]	A Scopus-Based Bibliometric Study of Maritime Research Involving the Automatic Identification System	A study about a maritime network that uses AI to recognise different docking structures with over 90% accuracy using low-resolution sensors. The important how AI can revolutionise industries and make processes more efficient. In this research, the study applied a bibliometric analysis on AI applications in various fields, which yielded a high number of citations compared to previous maritime studies.	2021
Yan R.; Wang S.; Cao J.; Sun D. [34]	Shipping Domain Knowledge Informed Prediction and Optimization in Port State Control	The new inspection templates introduced in the optimisation models have been found to be highly effective in detecting deficiencies in vessel traffic flow and environmental factors. The proposed PSCO scheduling model, which uses XG Boost predictions as inputs, has been shown to be more than 20% better than the current inspection scheme. This optimisation model is expected to significantly improve computation efficiency and model flexibility, enabling it to be a valuable tool for port authorities to enhance maritime safety and navigation.	2021
Chae, GY; An, SH; Lee, CY [3]	Demand Forecasting for Liquified Natural Gas Bunkering by Country and Region Using Meta-Analysis and Artificial Intelligence	In the field of energy, there are two approaches that are commonly utilised: top-down and bottom-up. The top-down approach involves making predictions at the highest level and then calculating prediction values based on the proportions of the components. This method is ideal when the study have access to the entire dataset. On the other hand, the bottom-up approach is used when data is available for each individual component. In the case of global LNG bunkering demand, the top-down approach was carried out.	2021
Zhang, XY; Wang, CB; Jiang, LL; An, LX; Yang, R [39]	Collision-avoidance Navigation Systems for Maritime Autonomous Surface Ships: A State-of-the-Art Survey	As industry move forward with the development of technology, human is facing a significant positive impact on the navigation of maritime autonomous surface ships (MASS). This progress is creating exceptional opportunities for coordinated and interconnected operations within maritime environments. Through a comprehensive study of existing collision avoidance and action planning technologies, it has been noted that collision-free navigation would greatly benefit the integration of MASS autonomy in various maritime scenarios.	2021
Liu, RW; Nie, JT; Garg, S; Xiong, ZH; Zhang, Y; Hossain, MS [17]	Data-Driven Trajectory Quality Improvement for Promoting Intelligent Vessel Traffic Services in 6G-Enabled Maritime IoT Systems	Researchers propose a two-phase data-driven machine learning framework to improve vessel trajectory records from AIS networks. The framework includes a clustering method and BLSTM-based supervised learning to restore degraded points. This could impact the maritime industry and promote IoT integration. They're collecting data from AIS and vessel systems and working on developing vessel manoeuvring guidelines for ports using AI and DBSCAN. Results will help propose guidelines for the development of autonomous vessels.	2021

Munoz, JA; Perez-Fernandez, R [21]	Adopting Industry 4.0 Technologies in Shipbuilding Through CAD Systems	This study explained an important method that can correctly analyse data, transform it into information, and apply it to improve design, manufacturing, operation, and maintenance processes will be successful in the ongoing industrial transformation. For example, vessel design can be significantly streamlined by using this method. This paper also explores practical use cases of this method, specifically machine learning, in the shipbuilding design phase.	2021
SA. Roslan, F. Yakub, S. Rambat, S. Munawwarah, M Saidin, F. Liana, NM. Maruai, MSM. Ali, AF. Mohammad [4]	The Novel Method in Validating the Spectral Wavelength Optimization to Determine Archaeological Proxies by the Integration of Aerial and Ground Platforms	In this study, researchers introduced a new method for identifying optimal spectral wavelengths to enhance the detection of buried archaeological features. It compares eight different spectral wavelength ranges and indices and applies the "Constant Experimental Evaluation" (CEE) method to improve results, identifying NIR = 0.783 µm and Red = 0.627 µm as optimal wavelengths along with a 50% image enhancement. This technique is valuable for detecting archaeological sites with distinct spectral differences from their surroundings.	2024

2.3 Eligibility and Exclusion Criteria

Our team has conducted a thorough and precise research study on the evolution of AI in the maritime industry. We have taken great care in selecting and analysing the most reliable and relevant journal articles that are published in English and listed in social science-based indexes. This meticulous process has allowed the authors to gain an extensive understanding of the subject matter over a period of three years. Table 2 shows further insights into the methodology and findings.

Table 2
Exclusion and inclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Journal articles	Journals (review), chapters in a book, book, book series, conference proceeding
Language	English	non-English
Timeline	2021 till 2024 (years)	before 2021
Context	Global	
Subject area	Maritime industry, social sciences, computer science, technology	all others except the mentioned

2.4 Systematic Review Process

Throughout a systematic review process, we focused on ensuring the utmost reliability and accuracy of this research. Our approach involved carefully identifying relevant keywords for this search process, including "artificial intelligence" and "maritime industry," as outlined in Table 3.

Table 3
The search string utilised regarding the systematic review process

Databases	Keywords
Web of Science	(ALL= (artificial intelligence)) AND ALL= (maritime industry) and Article (Document Types) and English (Languages) and 2024 or 2022 or 2021 (Publication Years)
Scopus	TITLE-ABS-KEY ("artificial intelligence") AND ("maritime industry") AND PUBYEAR > 2020 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBSTAGE, "final"))

We then meticulously screened and removed articles that did not meet this study's inclusion and exclusion criteria, ultimately discarding 19 papers out of the 168 eligible ones. We further narrowed down our selection by accessing full articles and excluding 115 that did not focus on artificial intelligence technology and maritime industry or were not empirical articles. Finally, we conducted a qualitative analysis of 34 articles, which is demonstrated in Figure 2.

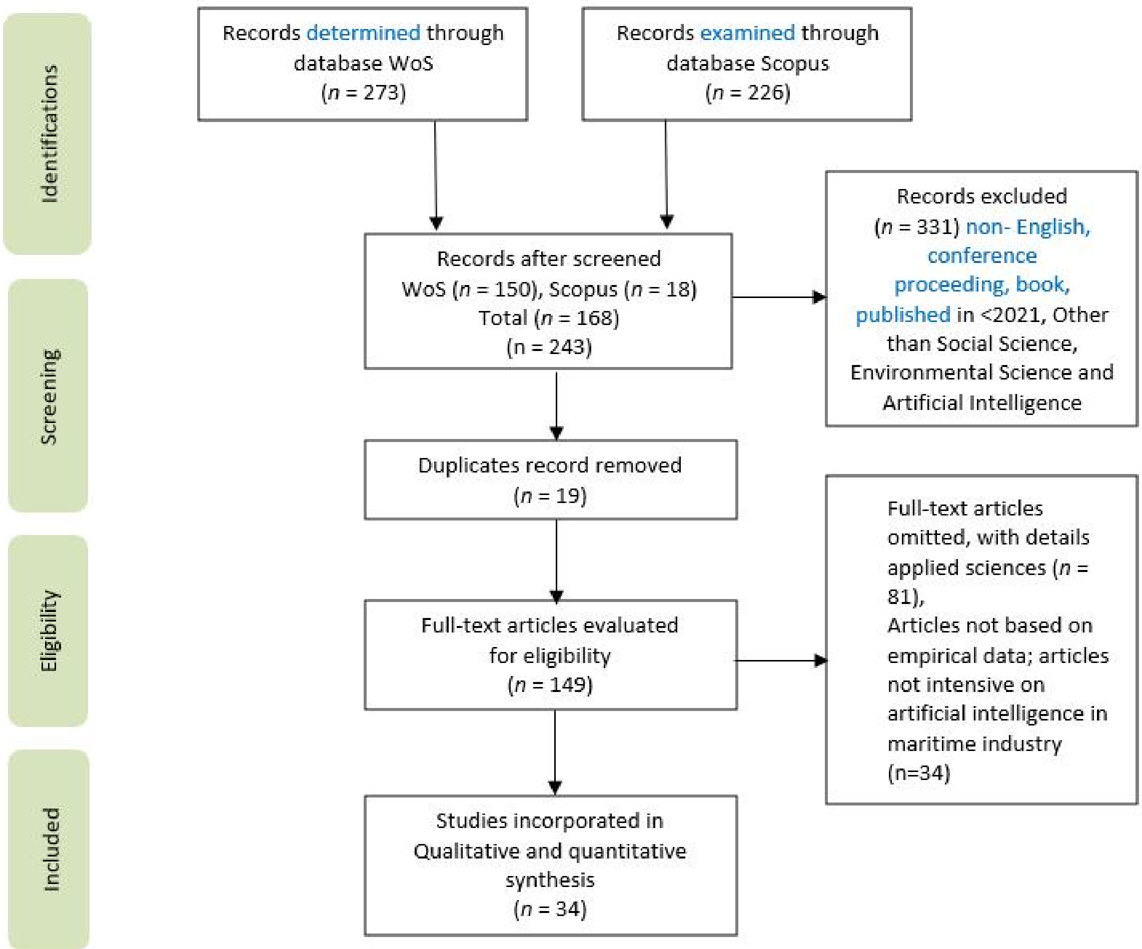

Fig. 2. Flow diagram with respect to article selection (Source: [41])

2.5 Data Abstraction and Analysis

During a review process, we carefully examined the selected studies to identify the main themes and subsequently drew out subthemes to further develop them. In order to maintain the accuracy and objectivity of the review, we conducted a thorough analysis of statements that effectively captured the essence of the studies. To establish meaningful and coherent themes, we performed data encoding. This process of analysis and decoding led this study to identify three primary themes, which were then carefully examined to ensure logical consistency among the themes and subthemes. Finally, experts with extensive knowledge of both qualitative and quantitative approaches reviewed the final articles to ensure their applicability and clarity of classification.

3. Discussions

3.1 Role of Artificial Intelligence Technology in the Maritime Industry

The introduction of AI technology in the maritime industry has resulted in significant advancements, reducing errors caused by human intervention and enhancing operational efficiency. AI-equipped autonomous vessels can detect potential collision risks and navigate without constant human supervision [6,13,39]. Real-time data analysis by AI algorithms enables suggestions of the most efficient routes, resulting in reduced fuel consumption and travel time. AI-powered equipment monitoring systems can predict maintenance requirements, thereby minimising downtime and maintenance costs. Machine learning models based on historic data can predict potential risks and hazards, enabling proactive safety measures. AI optimises engine performance, reducing fuel consumption and contributing to environmental conservation [28]. AI-powered robotics manage cargo loading and unloading with efficiency, ensuring timely deliveries and reducing losses from spoilage or damage. The use of AI in predictive analytics is set to transform conventional methods. This conversation covers the complex array of obstacles, such as data quality concerns, the interpretability of models, and the inherent intricacy of implementation [9,40]. AI processes vast amounts of weather and oceanographic data, enabling accurate and timely weather forecasts. Autonomous underwater vehicles gather oceanographic data to aid research and environmental monitoring. AI-powered surveillance systems can detect unusual activities and potential security threats in ports or seas, enhancing maritime security. AI-based simulators offer realistic training scenarios for crew members to prepare them for various operational challenges. The possibilities of AI in the maritime industry are endless and have the potential to revolutionise the industry.

3.2 Challenges in Adapting Artificial Intelligence Technology in the Maritime Industry

The maritime industry generates vast amounts of data, but it can vary in quality, accuracy, and consistency. To ensure reliable outcomes, AI systems heavily rely on high-quality data. Protection of sensitive information such as vessel routes, cargo details, and port operations is crucial to maintain operational integrity and confidentiality [7,34]. Standardisation of data formats and communication protocols across different maritime systems and stakeholders is necessary to enable seamless integration of AI applications and data sharing. Effective collaboration between AI systems and human operators is crucial as AI technologies become more advanced. Ensuring compliance with existing regulations while implementing AI systems can be complex. The initial costs of adoption may be a challenge for smaller operators. Trusting AI systems with critical decisions requires demonstrating their reliability and accountability. While AI can contribute to fuel efficiency and sustainability, the energy consumption and environmental impact of AI systems themselves need to be considered. AI systems must be adaptable to dynamic environments. Overcoming resistance and fostering a culture of innovation can be challenging. Collaboration among industry stakeholders, regulatory bodies, technology providers, and research institutions is essential.

Constructive strategies for AI implementation, data quality, and security, and continuous training and development of the workforce can facilitate the successful adaptation of AI technology in the maritime industry [40]. Another significant hurdle is ensuring that AI powered systems are robust enough to handle the varied types and scales of data generated in maritime scenarios. This includes data from sensors on vessels, satellites, and weather stations, each of which provides different types and formats of data that must be integrated and processed by AI systems [19]. In addition, obstacle is the need for improved fusion of multimodal data, such as data from radar, sonar, and AIS sensors, to provide a comprehensive understanding of the maritime environment [28,33]. Finally, determining which tasks can be practically performed using online learning capabilities is crucial in real time operations, where sensor data must be processed on the fly for tasks such as refining a previously learned model. Overall, addressing these challenges is essential for the successful implementation of AI technology in the maritime industry.

3.3 Digitalisation and Smart Shipyards

It is fascinating how the maritime industry is leveraging data analysis and AI-driven insights to improve operational efficiency and safety. An article that talks about the fusion of 5G and 6G wireless systems with the maritime IoT, which is leading the industry towards innovative, technology-driven solutions [20]. It is interesting how the integration of AIS, GIS, and e-charts can enhance navigational safety and efficiency by providing a comprehensive analysis of the relationship between vessel traffic flows and marine accidents [7,16]. Furthermore, some articles explained the implementation of smart shipyards, which is a great example of how the convergence of technologies can optimise vessel design, manufacturing, and operational processes [21,33]. These innovations have the potential to revolutionise the industry and foster a safer and more efficient maritime environment. While acknowledging potential cybersecurity threats, maritime organisation needs to remain optimistic that able to face these challenges and continue advancing towards a brighter future.

3.4 Navigational Safety and Environmental Impact

It is important to understand how the organisation in maritime is prioritising navigational safety and environmental sustainability in their pursuit of innovative and technology-driven solutions. The authors encountered an article discussing potential cybersecurity threats faced by autonomous vessels and the maritime industry due to the integration of advanced technologies [30]. It is important to have comprehensive strategies for cyber risk mitigation to ensure the safety and security of the industry. In other articles, an explanation about a predictive model for vessel trajectory that uses AIS data denoising and predictive modelling to mitigate navigational risks [6,20]. This is a great example of how the integration of technologies can lead to safer and more efficient maritime operations. Overall, it is inspiring to bring the industry's commitment to safety and sustainability, and optimistic about the potential for continued advancements in these areas.

4. Conclusions and Future Research

The integration of advanced technology, particularly AI, has undoubtedly shown high potentials in bringing significant benefits to the maritime industry. AI solutions have been proven to enhance decision-making, reduce human error, optimise resource utilisation, and improve safety standards, among other benefits. The benefits of AI in the maritime industry range from predictive maintenance to autonomous navigation, providing much-needed support in various aspects of the industry's operations. Despite the progress, there are still several areas that require further research and exploration to optimise AI's potential in the maritime industry. One of the critical areas is investigating robust data security and privacy frameworks to ensure that confidential information remains secure while utilising AI-powered tools. Moreover, developing comprehensive regulatory frameworks is also necessary to ensure that the industry adheres to ethical standards and promotes responsible AI use.

Effective human-machine collaboration models are also crucial to maximise the benefits of AI solutions. The maritime industry is human-centric, and AI should serve as a tool to support human decision-making processes. Besides that, collaboration between humans and machines should be seamless, and the AI system must be capable of effectively communicating with its human counterpart. In addition, minimising the industry's environmental footprint is also an area that needs attention. AI-powered solutions can be used to optimise fuel consumption, reduce emissions, and enhance overall environmental sustainability [19]. Encouraging collaboration and knowledge sharing among industry players can promote innovation and the development of new AI-powered tools and solutions.

Lastly, ethical standards must be adhered to in all aspects of AI usage, including development, deployment, and use. This ensures that AI solutions do not cause harm to individuals or society. By addressing these areas, the maritime industry can create a safer, more efficient, and environmentally responsible sector driven by AI innovation.

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