Digital Horizon: Assessing Current Status of Digitalization in Maritime Industry

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This study addresses the critical role of maritime transport, which accounts for a significant part of world trade, but faces environmental challenges due to its dependence on the combustion of conventional fuels. The study focuses on the fast-growing area of digitalization in the maritime industry as a solution and uses a bibliometric analysis to assess trends, country participation, patents, and influential journals. China leads in both publications and patents, with Ocean Engineering emerging as one of the most important journals. The study identifies modern technologies such as IoT, Blockchain, AI and Neural Networks as crucial to overcoming the challenges facing the industry. However, it also points to obstacles, including the need for advanced text analytics tools and interdisciplinary research. The integration of previous research efforts highlights gaps and the dynamic nature of the field. Implications for future research emphasize international collaboration, understanding the patent landscape and consideration of ethical and regulatory factors. The discussion highlights the transformative potential of AI, IoT, Big Data Analytics, and Blockchain in maritime digitalization and emphasizes the importance of balancing technological advances with safety and sustainability. In summary, the study provides valuable insights into the progress of maritime digitalization. It provides a basis for future research and highlights the potential for efficiency, safety and sustainability improvements that require a cautious and balanced approach.

KEY WORDS

~ Intelligent maritime transportation systems
~ Neural Networks
~ Digitalization
~ Blockchain
~ IoT

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1. INTRODUCTION

Maritime transport is the key factor of international trade and the global economy. With more than 80% of the world's trade volume carried by maritime transport and an average annual growth rate of 2.1% expected from 2023 to 2027 (UNCTAD, 2022), the importance of the industry becomes clear as higher shipping costs and poorer maritime connectivity subsequently lead to higher inflation, food shortages, and supply chain disruptions - all features of the current global crisis. The maritime industry also has environmental implications, as it is a growing source of air pollutants and greenhouse gas (GHG) emissions, accounting for 2.89% of the global anthropogenic emissions (Fourth Greenhouse Gas Study 2020, 2020). Unfortunately, a major problem persists in the shipping industry, where most containerships, cruise ships, tankers, and cargo ships rely on the combustion of fuel oil. In total, 90,000 ships consume 370 million tons of heavy fuel oil and release 20 million tons of nitrogen oxides into the atmosphere (MARITIME FORECAST TO 2050, 2019). This problem is expected to worsen if no action is taken. According to the *Maritime Forecast to 2050* report by experts at DNV GL, air pollution is expected to increase by at least 50% by 2050 at best and up to 250% at worst (MARITIME FORECAST TO 2050, 2019). Furthermore, a study by the European Parliament and the International Convention for the Prevention of Pollution from Ships (MARPOL), Annex VI, shows that shipping will be responsible for one-fifth of the global CO_2 emissions (Agarwala *et al.,* 2021). Considering that the International Maritime Organization (IMO) has adopted a strengthened strategy to reduce greenhouse gas emissions and a set of mandatory measures to improve the energy efficiency of ships (Amendments to the Annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 2011; Revised GHG reduction strategy for global shipping adopted, 2023.), the scientific community and the shipping industry are working together to explore various approaches to achieve these goals. Potential methods include component redesign (Krčum *et al*., 2021) and industry-wide process changes such as speed optimization (Psaraftis and Kontovas, 2014). A promising trend that goes hand in hand with emissions reduction, fuel efficiency, and overall improvement is the process of digitalization. The traditional maritime sector is gradually embracing digital technologies to improve efficiency, safety, and sustainability. However, despite its importance to global trade, the maritime transport industry is lagging behind in digitalization as highlighted in Sanchez-Gonzalez *et al.* (2019). This underscores the need for further investigation, illustrated by the successful implementation of unmanned vehicles in the development of the ferry *Folgefonn* (Wartsila tests automated dock-to-dock technology, 2018). The research highlights several promising areas for the application of digitalization in the maritime industry, such as navigational aids, fisheries management, conservation, additive manufacturing, and cloud computing. A critical aspect that needs to be improved is digital security to ensure the safe integration of other digital domains. The disadvantage of implementing vital systems interconnected via the Internet (in this case using the IoT) is the increased vulnerability to cyberattacks, as outlined in Akpan *et al.* (2022) for the maritime sector, and another emerging disadvantage is the need for personnel that can adapt to the changing infrastructure (knowledge of communication systems and digital measurements or software analysis) (Deaconu *et al.,* 2021).

To appropriately map out the direction for future research, it is crucial to begin by examining the current landscape of knowledge. The primary goal of this study is to present a comprehensive review of the current state of knowledge regarding the digitalization of the maritime industry. As part of this study, a bibliometric analysis is carried out to examine the key parameters of digitalization in the maritime industry. The focus of the analysis included the following key aspects:

- Annual publication trends,
- Active participation of countries,
- Most cited countries,
- Number of patents by country,
- Journals with the highest number of publications and citations

The main objectives were to identify trends in annual publications, measure country participation, identify the most cited countries, determine the volume of patents per country, and identify journals with notable publication and citation metrics.

By applying a bibliometric approach, this study sheds light on research progress, key digitalization issues and knowledge gaps in the maritime industry. The findings presented in this study should be a valuable resource for researchers and practitioners seeking a comprehensive understanding of the current landscape and future development of digitalization in the maritime sector.

2. PREVIOUS RESEARCH

This section serves as an initial exploration of previous research conducted using literature reviews and bibliometric analysis as research methods. Its main objective is to provide a basis for understanding previous research efforts and to facilitate the advancement of this knowledge. Fruth and Teuteberg (2017) conducted a thorough systematic literature review, centering on digitalization in maritime logistics which highlighted problem areas and suggested potential improvements, addressing issues associated with the utilization of Big Data which offers optimizing route, speed, tracking, and other characteristics, while also consequently introduces the associated risk of potential planning of attacks using the same data. Sanchez-Gonzalez *et al.* (2019) conducted a systematic literature review that shed light on the gradual integration of digitalization in maritime transport across multiple domains. Their review identified eight key areas, including autonomous ships, artificial intelligence, Big Data, virtual/augmented reality, Internet of Things, cloud computing, digital security, and additive manufacturing (3D printing), where digitalization has been applied. In addition, the study highlights the need for studies that address the integration of Artificial Intelligence and robotics in maritime transport, as there are few areas that have been formally researched. In the study conducted by Gil *et al*. (2020), bibliometric methods were used to scrutinize onboard Decision Support Systems (DSS) in the field of safety insurance and accident prevention, with particular attention to the challenges posed by increasing traffic and the size of ships. Balan (2020) focused on advanced information and computing technology in maritime transport and predicted a potentially disruptive impact on the industry from the incorporation of Big Data, Internet of Things (IoT), cloud computing, and autonomous ships. Tijan *et al.* (2021) conducted a study that focused on the drivers, success factors, and barriers associated with digital transformation in maritime transport. Given the limited research available, they also considered publications on digital transformation in the broader transportation context.

Overall, these studies provide valuable insights into the field of digitalization in the maritime industry. However, it is important to note that this overview is not exhaustive and further research is warranted given the rapid progress in this area.

3. RESEARCH STRATEGY

To obtain a comprehensive overview of the current state of digitalization in the maritime industry, the authors developed a methodological framework, which is shown in Figure 1. In creating their research design, they defined the scope of the study, goals, objectives, and research questions. The collection and processing of papers was done in several sequential steps that included preliminary screening and filtering based on exclusion criteria:

- Year of publication: only papers published between 2012 and 2023 were examined.
- Document type: the analysis was limited to articles.
- Research area: only relevant research areas were considered and irrelevant areas such as anthropology and psychology were excluded.
- Language: the analysis focused on papers written in English.

The authors then obtained results for the articles that met these criteria. They conducted a bibliometric analysis that included examining annual publication trends, identifying the most active countries in terms of publication trends and the total number of citations, identifying the most relevant journals based on publication trends and the total number of citations, analyzing the most cited research papers, and finally identifying the most active individual affiliations.

Furthermore, to gain a comprehensive understanding of each country's active affiliations, the authors also analyzed the *Espacenet* patent database (Espacenet, 2023) to identify the countries with the highest number of patents. Finally, the authors present their findings and outline possible directions for future research.

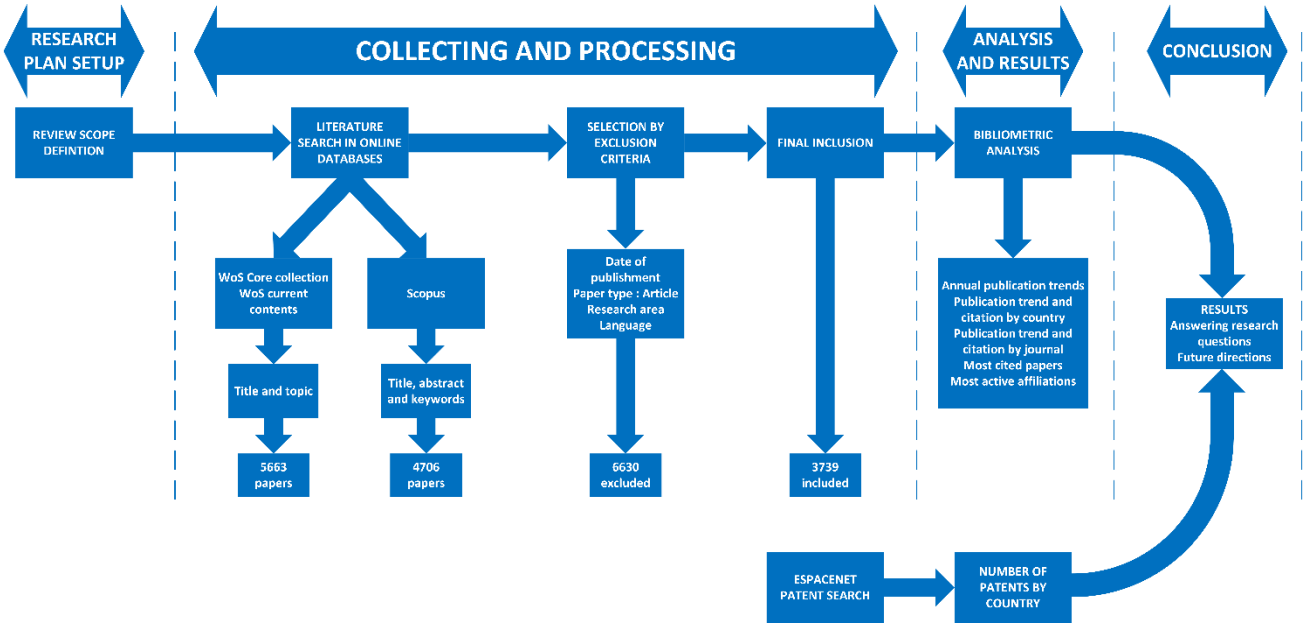

Figure 1. Developed methodology steps

In Figure 1, the authors focused primarily on the analysis of two well-known scientific databases, *Web-of-Science* (WoS) and *Scopus*. A specific query was used in the WoS search shown in Equation 1:

$$(TI = ((blockchain\ OR\ IoT\ OR\ Artificial\ Intelligence\ OR\ smart\ OR\ intelligent\ OR\ digital\ OR\ predictive\ OR\ maintenance\ OR\ machine\ OR\ learning\ OR\ twin\ OR\ neural\ OR\ network)\ AND\ (maritime\ OR\ shipping\ OR\ ship)))\ OR\ (TS = ((digitalization\ OR\ digitalisation)\ AND\ (maritime\ industry\ OR\ shipping\ industry)))\quad(1)$$

The same query was modified to match the search syntax in Scopus shown in Equation 2.

$$TITLE - ABS - KEY((blockchain\ OR\ IoT\ OR\ Artificial\ Intelligence\ OR\ smart\ OR\ intelligent\ OR\ digital\ OR\ predictive\ OR\ maintenance\ OR\ machine\ OR\ learning\ OR\ twin\ OR\ neural\ OR\ network)\ AND\ (maritime\ OR\ shipping\ OR\ ship))\quad(2)$$

Both databases use an advanced search engine based on Boolean algebra that allows the entry of a variety of parameters to perform the most precise search possible. However, an unfortunate aspect of this approach is the existence of numerous associations with the topic under study, which makes it difficult to capture all relevant keywords. It is important to highlight that the search in the Web-of-Science was primarily based on

the title and topic of the paper, while the search in *Scopus* included the title, abstract, and keywords of the paper. After applying the aforementioned exclusion criteria, a total of 3,739 papers were included in the bibliometric analysis.

In order to increase the efficiency of future searches for relevant literature, an additional research step was made to map the frequently used keywords in the analyzed literature. Using the *VOSviewer* software, the authors visualized and examined the keywords of the original authors. This approach aimed to refine the literature search process in order to achieve better results.

4. BIBLIOMETRIC ANALYSIS RESULTS

This chapter of the study presents the comprehensive results of a careful bibliometric analysis that sheds light on the dynamic landscape of maritime digitalization research. The different facets of this analysis are divided into sub-chapters, each of which deals with different dimensions of scientific output and influence. The following sub-chapters navigate through the wealth of data and provide insights into annual publication trends, actively participating countries, the most important journals in the field, and a nuanced mapping of common keywords.

4.1. Annual Publication Trends

The chapter presents an examination of annual publication trends in maritime digitalization, analyzing the patterns evident in the *Scopus* and WoS databases. The analysis, presented in Figure 2, reveals an increase in research focus, particularly in 2022, characterized by the simultaneous appearance of a significant number of articles in both databases (229 articles in *Scopus*, and 412 articles in WoS). This section illustrates the evolution of the scientific discourse and the fast-growing interest in maritime digitalization, with the *caveat* that the survey was completed in September 2023, leaving room for further growth in the current year.

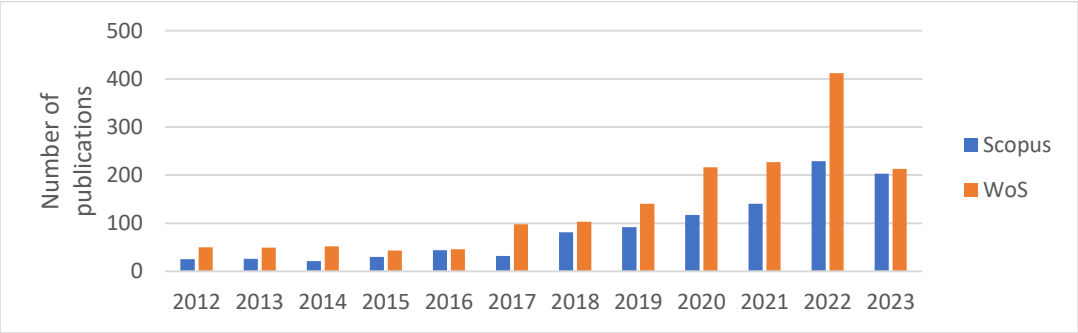

Figure 2. Annual publication trends in maritime digitalization

4.2. Active Participating Countries

To define the active countries participating in the relevant research area, the number of countries of publication in both databases has been analyzed and provided in Figure 3. The largest number of publications come from China (PRC), followed by the United States of America (The USA), England, and South Korea.

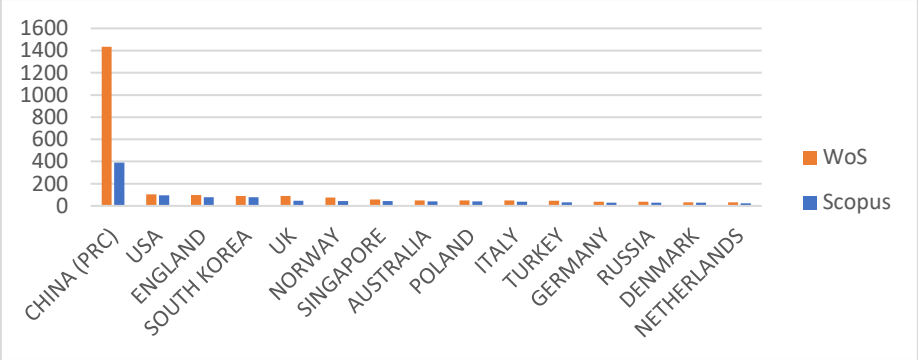

Figure 3. Number of publications per country

In order to get the full picture of the active participation of individual countries, the number of citations per country (without self-citations) have been analyzed and the top 10 (in each database) are presented in Table 1.

No.	*Scopus*		WoS	
1	China (PRC)	7,111	China (PRC)	12,715
2	The USA	2,042	The USA	1,056
3	The UK	1,849	England	774
4	South Korea	1,171	South Korea	631
5	Germany	841	UK	598
6	India	774	India	544
7	Norway	734	Italy	507
8	Italy	663	Australia	445
9	Canada	580	Canada	426
10	Poland	562	Norway	413

Table 1. Top 10 cited countries in each database

The analysis, which was completed in September 2023, shows consistent patterns in the active participation of countries across two parameters and databases, i.e., China, the USA, England (the UK) and South Korea. In assessing their participation, we conducted a comprehensive examination of patent numbers for each accessible country using *Espacenet* (Espacenet, 2023), using identical keywords as input. It is important to emphasize that WIPO corresponds to *World Intellectual Property Organization*. As shown in Figure 4, China (PRC) is the leader in patent holdings in this area, followed by the USA and Japan.

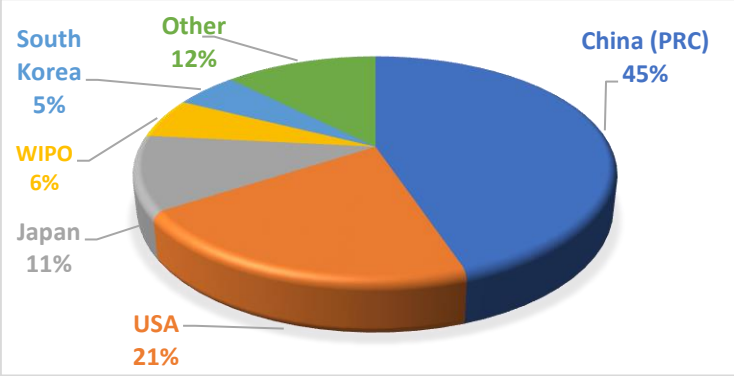

Figure 4. Number of patents per country

4.3. Core Journals in the Field

To identify the most relevant journals in the field, the authors performed an analysis in both databases by extracting the number of articles published and the total number of citations in each field. The results for each database are displayed in Table 2 and Table 3.

No.	Scopus		WoS	
1	Ocean Engineering	195	Ocean Engineering	151
2	Journal of Marine Science and Engineering	50	Journal of Marine Science and Engineering	110
3	IEEE Access	42	Sensors	64
4	IEEE Transactions on Intelligent Transportation systems	40	IEEE Access	56
5	IEEE Transactions on Geoscience and Remote Sensing	39	IEEE Transactions on Intelligent Transportation systems	40

Table 2. Top 5 journals by number of publications in each database

No.	Scopus		WoS	
1	Ocean Engineering	3,281	Ocean Engineering	834
2	IEEE Transactions on Geoscience and Remote Sensing	1,151	IEEE Access	492
3	IEEE Access	755	Journal of Marine Science and Engineering	477
4	IEEE Transactions on Intelligent Transportation systems	720	Remote Sensing	425
5	Journal of Marine Science and Engineering	260	Sensors	330

Table 3. Top 5 most cited journals in the relevant field

From the above tables, it is clear that *Ocean Engineering* is an outstanding journal in the field, excelling both in the number of articles published and in the number of citations. This underlines the great importance of the journal in this field.

4.4. Frequent Keyword Mapping

In Figure 5, the authors used the software *VOSviewer* for their analysis, in which they integrated the authors' keywords from both databases to visualize the common occurrence of keywords.

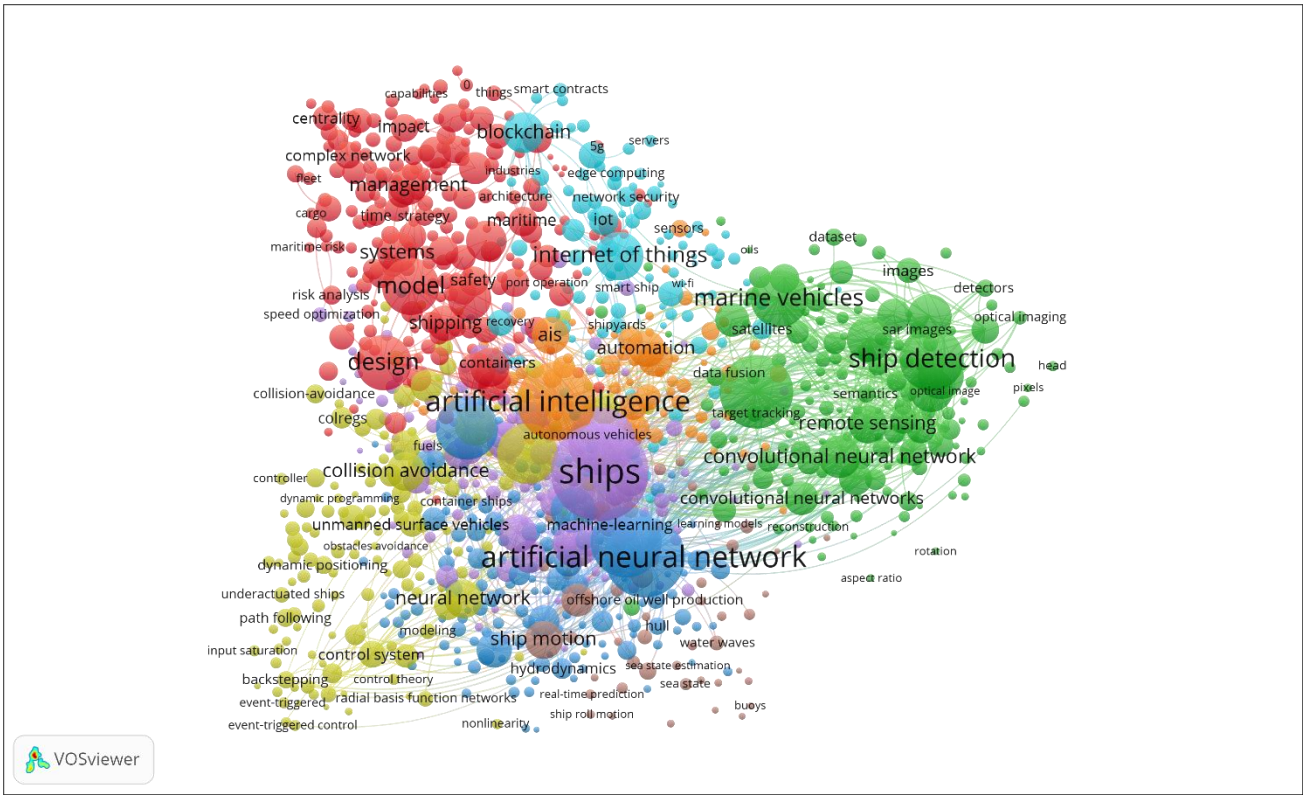

Figure 5. Visualization of keyword co-occurrence

Figure 5 shows that the most common keywords closely match the search query, such as *ships*, which naturally correlates with the field under study. Although the digitalization of the maritime industry spans various research areas, most of these recurring keywords are related to various forms of neural networks. These neural networks are interwoven with various research efforts, including *target tracking*, *remote sensing*, *collision avoidance*, *speed optimization*, *optical imaging,* dynamic positioning, etc. They form the basis for various developments that use machine learning, particularly artificial intelligence, to achieve the desired goals.

The presence of modern technologies such as *Internet-of-Things*, *Blockchain*, *Artificial Intelligence*, and *Neural Networks* plays an important role in the digitalization of the maritime sector. It is important to acknowledge that capturing all relevant keywords in the query search is challenging as there are a variety of associations within the field under study. A second challenge that arises is that the software does not distinguish between singular and plural forms of the same term, as in *convolutional neural network* and *convolutional neural networks*, showcasing them as separate terms.

5. DISCUSSION

This chapter discusses the results of the investigation, which are divided into two sub-chapters. The following subchapters present key findings from this analysis, highlighting the importance of digitalization, global participation, patent landscape, key journals, and emerging technologies. In addition, challenges, interdisciplinary aspects and avenues for future research directions are discussed to provide a foundation for the ongoing transformation of the maritime industry.

5.1. Extraction of Results and Implications for Future Research

This study provides a comprehensive overview of the current state of knowledge on the digitalization of the maritime industry, focusing on bibliometric analysis. This approach includes quantitative analysis of research publications, patents, and other relevant data to provide insights into research trends and key players in the field. The key findings based on the information presented in the research are:

a) Importance of digitalization in the maritime industry

The analysis shows an increasing interest in maritime digitalization, as evidenced by an increasing number of research publications over the years. This trend highlights the growing importance of digital technologies in the maritime industry. Researchers can draw on this information to explore emerging topics and technologies that are gaining traction.

b) Global participation and collaboration

The study identifies China, the USA, England, and South Korea as the most active countries in maritime digitalization research. This suggests that these countries are at the forefront of advances in the field. Future research could explore the nature and impact of international collaboration in this area and how it contributes to knowledge sharing and innovation.

c) Patent analysis

China is the leader in terms of the number of patents related to maritime digitalization. Understanding the patent landscape can shed light on which countries are driving innovation and provide guidance to policymakers and industry stakeholders in promoting innovation and protecting intellectual property.

d) Key journals and citation trends

The prominence of the journal *Ocean Engineering* suggests that it is a central hub for disseminating research results in the field of maritime digitalization. Researchers can examine the content of this journal to gain deeper insights into recent developments. In addition, an analysis of citation trends can reveal influential articles and research areas that have a significant impact on the field.

e) Keyword analysis

Keyword analysis shows the relevance of modern technologies such as *Internet of Things* (IoT), *Blockchain*, *Artificial Intelligence* (AI), and *Neural Networks* in the digitalization of the maritime sector. Researchers can look at these keywords to explore how these technologies are being used and what impact they could have on the future of the industry.

f) Challenges and opportunities

The aforementioned challenges, such as capturing all the relevant keywords and distinguishing between singular and plural, highlight the need for more sophisticated text analysis tools and methods. Researchers can work to develop improved techniques for information retrieval and analysis in the context of maritime digitalization.

g) Interdisciplinary research

The presented study mentions that the digitalization of the maritime industry spans several research areas. This indicates an interdisciplinary nature of the field, allowing researchers from different backgrounds to collaborate and contribute with their expertise. Future research can explore how different disciplines intersect in this context.

h) Future research directions

The presented results suggest that further research is needed, given the rapid advances in the digitalization of maritime transport. Future studies can focus on filling the existing knowledge gaps such as exploring the societal and environmental impacts of digitalization in the maritime industry, and examining the ethical and regulatory considerations associated with the use of advanced technologies, especially in the case of autonomous vessels.

In summary, this study provides valuable insights into the current state of knowledge in maritime digitalization and lays the foundation for future research directions. Researchers can use this information to guide their investigations, collaborate with international partners, and contribute to the ongoing transformation of the maritime industry through digitalization.

5.2. Future Research Directions Concerning Most Promising Digital Technologies

In this paper, we present an analysis of the existing knowledge in the field of maritime digitalization. We identify possible future directions, categorized by underlying digital technologies.

Artificial intelligence (AI) is at the forefront of the maritime digitalization process and is often employed alongside other digital technologies. The European Commission recognizes the central role of AI and has developed a strategy to streamline research and policy options to regulate AI (European Commission, 2022). AI is the main driver for the realization of autonomous (unmanned) vessels responsible for tasks such as recognition, decision-making, and execution of actions. The degree of autonomy determines whether crew members or land-based control centers oversee the decision-making process and action outcomes (Yoo and Jo, 2023). In this context, AI applications include various functions, including vessel and obstacle detection to avoid collisions (Zhou and Zhang, 2023). In addition, AI helps to optimize routes, determine cruising speed, and optimize operational activities such as asset management, fleet coordination, and compliance monitoring (Harrie Bastiaansen *et al*., 2019; Lambrou *et al*., 2019). However, these implementations need to address cybersecurity concerns, although some studies suggest solutions (Lehto and Pöyhönen, 2023; Mahmood et al., 2022; Progoulakis *et al.,* 2023). As highlighted by distinct research studies, this area needs further in-depth research. The complexity of regulations, especially with respect to liability in collision scenarios, is a major challenge (Elnoury and Farag, 2023).

AI can be combined with various sensors to improve decision making, optimize business processes, and reduce negative environmental impacts. According to CRISTEA, the combination of Automatic Identification System (AIS) data with AI techniques will have a major impact on shipping analytics services, making strategic and operational information about ships (or fleets) more readily available worldwide. However, it is important to note that AIS has vulnerabilities due to its open system nature and transmission on dedicated VHF frequencies. In future studies, care should be taken to ensure that the data are used without detrimental consequences as shown in the analysis of AIS spoofing in a case study by Androjna *et al*. (2021). The widespread trend associated with the integration of AI and sensors is the *Internet of Things* (IoT). The IoT plays a critical role in various segments of the maritime industry, such as monitoring conditions and critical equipment on board, remote maintenance of equipment, control of ship loading, advanced weather forecasting, automation of cargo handling equipment, streamlining port operations, and ship design (Hiekata *et al*., 2021). However, as with any connection to the Internet, there is an increased risk of security breaches and potential data manipulation. *Big Data Analytics* (BDA) plays a critical role in harnessing the vast amounts of data collected by IoT. It enables AI-powered assessment of factors such as weather conditions, vessel position, speed, and electronic charts, leading to improved safety of navigation by detecting anomalies and anticipating risks (Ma, 2020). The BDA also contributes to improved fleet planning, optimized vessel operations, and schedule management (De La Peña

Zarzuelo *et al*., 2020; Johansson *et al*., 2021). Nevertheless, as the analyzed research papers in the present study have emphasized, policy guidance needs to be further explored to fully exploit the benefits of these technologies without compromising data security and privacy.

In the maritime domain, digital twins are an interesting topic. They offer benefits in maintenance planning, predictive maintenance, fault prediction, real-time fault detection, and onboard process optimization. This includes reducing fuel consumption, environmental impact, and overall costs. The main obstacle to the application of real-time digital twins is communication with the physical object, as stated in Assani *et al.* (2022).

Blockchain technology, which is recognized as the leading digital security solution, works as a decentralized and immutable digital ledger. It securely records and verifies transactions among multiple participants to ensure transparency, trust, and tamper resistance (Lafourcade and Lombard-Platet, 2020). Blockchain can digitalize operational processes such as documentation, bill of lading, and customer clearance, mitigating operational risks for container ships (Balcı, 2021; Nguyen *et al.*, 2022; Perkušić *et al*., 2020). A comprehensive study by (Abdallah *et al*., 2023) examines the potential use of blockchain technology in the maritime industry, including its benefits, potential applications, limitations, and challenges. The study highlights the need to adapt *Blockchain* technology to the needs of the sector, with the aim of revolutionizing the industry through improved security, transparency, efficiency, and trust. It proposes a theoretical conceptual hypothesis for a re-imagined blockchain-based maritime ecosystem and offers valuable insights for academics, policy makers, and industry practitioners.

6. CONCLUSION

The paper has several limitations that should be noted. First, the software used in this study primarily identified the most frequently occurring keywords and their associations, as shown by the *singular and plural dilemma*. In addition, the basis of this study is a literature review, and given the rapid developments in the field, the current state of research presented here may quickly become outdated, a trend seen in many previous studies.

Nonetheless, the research presented in this paper provides valuable insights into the ongoing progress of maritime digitalization. These findings can serve as a solid foundation for future research in this area. Our analysis focused exclusively on two prominent databases, WoS and *Scopus*, which use advanced search engines based on Boolean algebra. The use of relevant keywords as input data was a limitation of the research as it proved difficult to capture all the relevant topics. This limitation stems from the extensive associations within the field studied, and the exclusion of articles that were not written in English also contributed to this limitation. It is important to bear these limitations in mind when interpreting our results. However, our bibliometric analysis provided a comprehensive overview of the existing body of knowledge, which in turn enabled the identification of potential avenues for future research.

In summary, digitalization is profoundly transforming the shipping industry, bringing unprecedented opportunities and challenges. The adoption of smart shipping, data-driven decision-making processes, and the integration of digital platforms offer the potential to significantly improve the efficiency, safety, and sustainability of the maritime sector. However, to fully realize the benefits of digitalization in the maritime industry, it is essential to address issues of cybersecurity, affordability, adapting laws and regulations to new technologies, and managing workforce transition. As the maritime industry continues its journey toward digitalization, finding the right balance among technological advancement, security, and sustainability will be critical to shaping its future.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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