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Exploring a decade of maritime transportation studies: Trends and developments

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Abstract

This study aims to identify trends and developments in maritime transportation research over the past decade using bibliometric analysis based on Scopus data. Bibliographic coupling and co-word analysis techniques were employed to evaluate research relationships, topic trends, and their impact. VOSviewer software was utilized to map the research network. The bibliometric coupling analysis revealed four major clusters, including sustainability strategies, operational optimization, digital transformation, and navigation safety. Meanwhile, the co-word analysis identified three dominant themes: maritime accident prediction, China's container trade growth, and sustainable maritime transportation strategies. Research trends indicate an increasing focus on digital technologies, such as artificial intelligence and the Internet of Things (IoT), in navigation and port management. Theoretically, this study enhances the understanding of the knowledge structure in maritime transportation. Practically, the findings provide valuable insights for industry stakeholders and policymakers in developing evidence-based strategies to improve the efficiency, sustainability, and safety of maritime transportation.

Keywords: Bibliometrics, Maritime Safety, Maritime Transportation, Research Trends, Sustainability.

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1. Introduction

Maritime transportation plays a crucial role in global trade and international supply chains, with approximately 80% of the total global trade volume relying on this sector [1]. Over the past decade, research in maritime transportation has experienced rapid development due to the growing demand for efficiency, security, and sustainability in the industry [2]. Emerging challenges such as regulatory changes, digitalization, and environmental sustainability have further emphasized the need for a deeper understanding of the evolution of research in this field.

The adoption of digital technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), has been increasingly implemented in navigation systems and port management to enhance operational efficiency [3]. However, digitalization in the maritime sector lags behind other industries, with many companies facing challenges in implementing complex digital systems [4]. Furthermore, sustainability issues have become a central focus in maritime transportation research, particularly in efforts to reduce greenhouse gas emissions and adopt environmentally friendly technologies [5]. With the increasing volume of trade and the growing complexity of challenges, a more comprehensive analysis is needed to understand research trends in maritime transportation. Such an analysis is essential to support more effective policymaking and drive industry innovation toward a more advanced and sustainable future.

Maritime transportation remains the backbone of global trade, with an increasing volume of cargo transported via sea routes each year [1]. As digital technology advances and sustainability concerns grow, research in maritime transportation has shifted from focusing primarily on regulations and policies to optimizing logistics and operational efficiency [6]. One of the primary challenges faced by this industry is the transition toward more environmentally friendly transportation systems through the adoption of renewable energy sources and emission reduction strategies [7].

Additionally, the digital revolution in the maritime sector has enabled the integration of advanced technologies such as artificial intelligence (AI) and the Internet of Things (IoT) to enhance operational efficiency and navigational safety [8]. However, despite these advancements, digitalization in this sector still encounters significant barriers, including infrastructure limitations and resistance to technological change [9]. With increasing regulatory pressures and market demand for more efficient and environmentally sustainable solutions, analyzing research trends in maritime transportation has become crucial to identifying innovations and strategies that can support the future sustainability of this industry.

Although maritime transportation has been a major topic in global research, there remains a gap in mapping key trends and developments in this field through a bibliometric approach. Several studies have highlighted the role of digitalization in maritime transportation, yet there is still a lack of comprehensive research on how these technological advancements contribute to the overall optimization of the maritime sector [10]. Additionally, existing research tends to focus on specific aspects, such as maritime traffic safety and risk mitigation, but has not thoroughly examined the relationship between technological innovation and port efficiency [5].

In the context of digitalization and big data integration, current studies are largely oriented toward technical analyses, with limited exploration of the economic impact of digital transformation in maritime logistics [11]. Therefore, a more comprehensive analysis is needed to identify publication patterns, dominant trends, and future research directions in maritime transportation studies. Such an investigation can provide valuable insights for academics, industry practitioners, and policymakers in developing more targeted strategies to enhance the efficiency and sustainability of global maritime transportation.

This study aims to identify research trends and developments in maritime transportation over the past decade using a bibliometric approach. Given the rapid growth of the maritime industry, it is essential to understand the patterns of scientific publications that contribute to innovation in this field [5]. This study will analyze influential publications, identify emerging research topics, and explore the relationships between various concepts in the maritime sector. Additionally, this study highlights the increasing dominance of digitalization and the implementation of new technologies in the maritime supply chain over recent years [11]. By conducting a bibliometric analysis based on data from Scopus and Web of Science, this research will map academic collaborations, citation trends, and the evolution of research topics from various perspectives, including sustainability, port efficiency, and maritime safety [10]. Thus, the findings of this study are expected to provide valuable insights for academics and industry practitioners in developing evidence-based strategies to enhance the efficiency and sustainability of global maritime transportation [2].

This study employs a bibliometric approach to analyze research trends and patterns in maritime transportation over the past decade. Data is collected from the Scopus database, one of the primary sources for evaluating the dynamics of academic publications in this field [5]. The bibliometric analysis is conducted using bibliographic coupling and co-word analysis techniques to identify research interconnections, topic evolution, and the academic impact of various publications [10]. Utilizing VOSviewer and Bibliometrics in R Studio, this study maps collaboration networks among authors, institutions, and countries actively engaged in maritime transportation research [11]. Additionally, this study explores current and emerging research trends. Thus, beyond providing insights into maritime transportation research trends, this study also offers a deeper understanding of the challenges and opportunities in the development of a digitally driven and sustainable maritime industry.

2. Literature Review

Research in maritime transportation over the past decade has demonstrated significant advancements across various aspects, including digitalization, safety, logistics efficiency, and sustainability. A study by Bai et al. [1] found that the primary focus of research has shifted from policy and regulation toward more efficient, integrated, and sustainable maritime transportation. Meanwhile, Alzate et al. [2] highlighted how Industry 4.0 has contributed to the optimization of maritime logistics, enhancing port competitiveness, and influencing economic factors within the global supply chain.

From a safety perspective, research by Skjong and GUEDES SOARES [12] indicates that although the maritime industry continues to grow, safety regulations face increasingly complex challenges due to the rising number of vessels and pressures from environmental policies. In line with this, Psaraftis [8] highlights that the development of regulations related to ship and port emission reductions has significantly influenced the design and operation of maritime logistics chains.

The advancement of digital technology has also had a significant impact on maritime transportation. Sanchez-Gonzalez et al. [3] found that although digitalization in this sector lags behind other industries, there has been an increasing adoption of technologies such as AI, big data, the Internet of Things (IoT), and cloud computing to enhance operational efficiency. Meanwhile, Pavlinović et al. [13] emphasized that digitalization not only improves efficiency but also plays a crucial role in reducing environmental impact through the implementation of green solutions.

Sustainability in maritime transportation has become a primary focus of recent research. Czermański et al. [14] discussed maritime decarbonization strategies, including European Union policies aimed at reducing carbon emissions by up to 70% by 2050. On the other hand, Georgakaki et al. [15] developed a model to estimate air emissions from ships using statistical data from the European Union, emphasizing that ship emission mitigation is a crucial factor in reducing the impact of climate change. These trends indicate that strict emission regulations, digitalization, and logistics efficiency will be the key drivers of maritime transportation development in the future.

3. Methodology

3.1. Bibliometric Approach

Bibliometric analysis is a quantitative approach that utilizes bibliographic databases (e.g., Web of Science and Scopus) to help researchers understand the knowledge structure within a specific field. This approach serves as a form of scientific mapping, producing visual representations of the structure within documents, journals, authors, and keywords as outputs [16].

There are five primary types of bibliometric analysis; however, this study applies two specific types that align with the research objectives, namely:

3.1.1. Bibliographic Coupling

Bibliographic coupling is a method that links documents sharing common references, known as "bibliographic coupling." This technique is used to determine the degree of similarity between two articles that cite the same references [17]. It is considered one of the most innovative citation-based methods and is highly suitable for analyzing current research trends in a specific field [18]. Bibliographic coupling is conducted by analyzing words in titles, abstracts, author names, and keywords. Clusters in this analysis are formed through inductive interpretation by the authors, connecting words with relevant relationships.

3.1.2. Co-word Analysis

Co-word analysis is an approach that calculates the frequency of keyword co-occurrence in publications [19]. This method is used to assess research development and identify future research directions [20]. The fundamental principle of this analysis is that when certain words frequently appear together, there is an underlying research concept connecting them [21]. Co-word analysis is the only bibliometric method that directly utilizes publication content to establish similarity measures in bibliometric analysis.

3.2. Research Design and Data Collection Procedure

To identify relevant publications, we utilized the following search string (Table 1) based on carefully selected keywords.

The table in the image provides keywords and justifications for the literature search. Here is the academic translation of this section while improving clarity and structure:

Table 1.
Search String in the Web of Science (WoS) Database.

Keywords	Justification
TITLE-ABS-KEY (“Maritime Transportation” OR “Sea Transportation” OR “Marine Transport”)	To identify relevant literature related to "Maritime Transportation," "Sea Transportation," or "Marine Transport."

Based on Table 1, the literature search in the Web of Science (WoS) database was conducted using the search string TITLE-ABS-KEY, which includes several terms related to Maritime Transportation, such as "Maritime Transportation," "Sea Transportation," and "Marine Transport." The purpose of using these keywords is to identify relevant literature broadly within the field of maritime transportation. The justification for employing this search string is to ensure that all studies related to sea transportation are captured in the search results, thereby providing more comprehensive coverage of the available research within this domain.

The process of searching and selecting journals in the Scopus database was conducted systematically, with data extracted on February 2, 2025, to identify literature related to maritime transportation. The initial search using the TITLE-ABS-KEY string with the keywords "Maritime Transportation" OR "Sea Transportation" OR "Marine Transport" yielded 6,669 journal articles. After filtering based on the publication year range 2015–2025, the number of journals was reduced to 4,629, excluding 2,040 journals. Subsequently, only journals classified as scientific articles ("ar") with final publication status ("final") were retained, resulting in 3,432 journals, while 1,197 journals were excluded. In the final selection stage, only journals categorized as "Journal" ("j") and published in English ("English") were included, maintaining 3,432 journals after removing 146. After completing all selection stages, a total of 3,286 journals were selected for analysis, ensuring that only high-quality and relevant journals were used in this study.

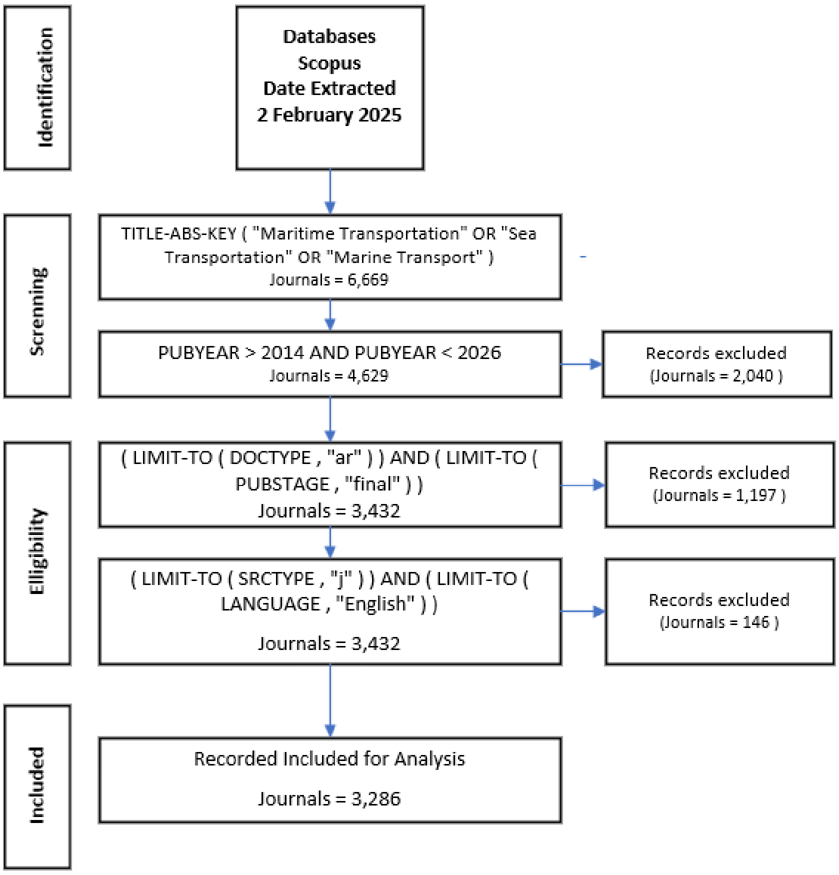

Figure 1.
Steps of the Analysis Process

4. Findings and Analysis

Figure 3 illustrates the trend in the number of publications related to maritime transportation, based on data retrieved from the Scopus database for the period 2015–2025. The literature search in Scopus was conducted on February 2, 2025.

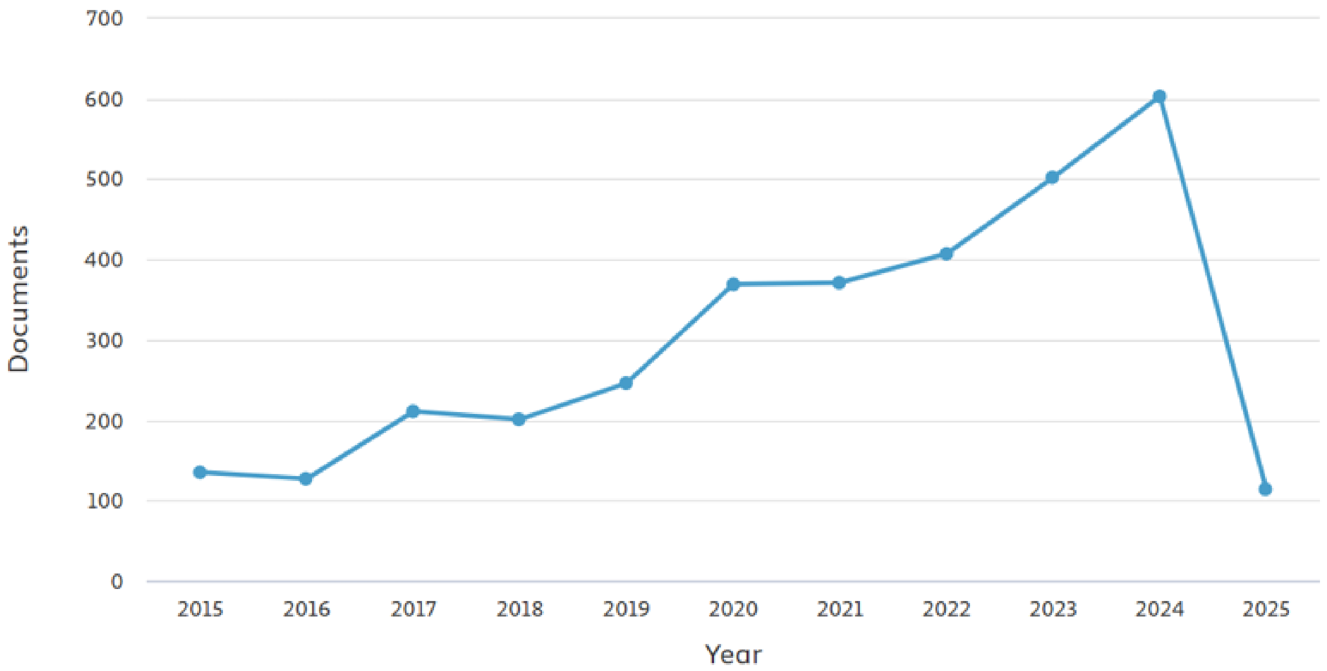

Figure 2.
Number of Publications and Citations on Maritime Transportation.

Based on Figure 2, the number of publications has shown a gradual increase from 2015 to 2024, with a significant rise after 2019, peaking in 2024 with approximately 600 documents. However, in 2025, the number of publications declined sharply, which could be attributed to incomplete data accumulation for the year or other factors affecting the availability of publications. Overall, this trend indicates that research in maritime transportation has expanded in recent years, with a notable increase in interest over the past decade.

4.1. Bibliographic Coupling

Out of the 3,286 documents analyzed, 68 documents met the threshold of 116 citations. These 57 documents formed six clusters. The top three documents based on Total Link Strength (TLS) are: Goerlandt and Montewka [22]– 121 TLS, Goerlandt and Montewka [23] – 114 TLS, Zhang et al. [24]– 90 TLS.

Table 2.
Top 10 documents in bibliographic coupling analysis.

Rank	Publication	Citation	Total link strength
1.	Maritime transportation risk analysis: Review and analysis in light of some foundational issues	279	121
2.	A framework for risk analysis of maritime transportation systems: A case study for oil spill from tankers in a ship–ship collision	218	114
3.	A method for detecting possible near miss ship collisions from AIS data	235	90
4.	An analysis of ship escort and convoy operations in ice conditions	130	88
5.	Towards the development of a system-theoretic model for safety assessment of autonomous merchant vessels	131	70
6.	A novel analytic framework of real-time multi-vessel collision risk assessment for maritime traffic surveillance	137	67
7.	Maritime Transportation Risk Assessment of Tianjin Port with Bayesian Belief Networks	146	60
8.	Marine transportation risk assessment using Bayesian Network: Application to Arctic waters	213	58
9.	System-theoretic approach to safety of remotely-controlled merchant vessel	119	48
10.	State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review	606	46

Figure 3 presents the network visualization of bibliographic coupling. The four clusters are visibly independent of one another. The following discusses current trends and future development of maritime transportation. The clusters are labelled based on inductive interpretation by revisiting representative articles in the clusters and synthesized based on common themes and research streams presented.

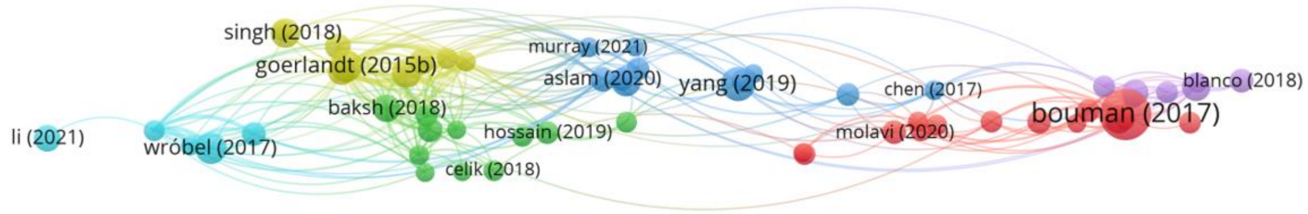

Figure 3.
Bibliometric Coupling Analysis on Maritime Transportation.
Source: Goerlandt and Montewka [23]**;** Baksh, et al. [25]**;** Hossain, et al. [26]**;** Murray and Perera [27]**;** Aslam, et al. [28]**;** Yang, et al. [29]**;** Chen [30]; Molavi, et al. [31] and Bouman, et al. [32]

4.1.1. Cluster 1 (Red) Sustainability, Operational Optimization, and Technological Innovation in Maritime Transportation.

Maritime transportation faces significant challenges in reducing environmental impact while enhancing operational efficiency. Bouman et al. [32] emphasize that no single solution can effectively mitigate greenhouse gas (GHG) emissions. However, a combination of advanced technologies and more efficient operational practices has the potential to reduce emissions by up to 75% by 2050. Measures such as improving ship design, adopting alternative fuels, and implementing stringent policies can significantly lower emissions per unit of cargo. Beyond sustainability, operational optimization plays a crucial role in reducing fuel consumption and logistics costs. Fagerholt et al. [33] demonstrate that strategic navigation, particularly in Emission Control Areas (ECA), helps ship operators adjust speed and routes to maintain efficiency. This approach allows vessels to comply with strict emission regulations while avoiding excessive fuel consumption. Moreover, sustainability and operational optimization are further reinforced through technological innovation in port systems. Molavi et al. [31] introduce the Smart Port Index (SPI) as an evaluation tool aimed at enhancing port efficiency and resilience. By incorporating key indicators in operations, environment, energy, and security, the SPI enables ports to adopt smart technologies that reduce congestion, enhance logistics transparency, and accelerate cargo handling processes. Overall, sustainability, operational optimization, and technological innovation are not standalone elements but rather integrated approaches that contribute to developing a more environmentally friendly and efficient maritime transportation ecosystem.

4.1.2. Cluster 2 (Green): Risk Analysis, Operational Safety, and Maritime Transportation Resilience

Maritime transportation faces various challenges, including accidents, natural disasters, and operational disruptions. Akyuz [34] developed a model based on the Analytical Network Process (ANP) and the Human Factors Analysis and Classification System (HFACS) to identify the primary causes of accidents related to human factors. Meanwhile, Baksh et al. [25] employed a Bayesian Network (BN) to assess accident risks in Arctic waters, emphasizing the impact of ice conditions on ship accident probabilities. On the other hand, the resilience of maritime transportation systems and ports has become a critical research focus. Hossain et al. [26] utilized a Bayesian Network to evaluate port preparedness in handling disruptions such as natural disasters and cyberattacks, highlighting that infrastructure maintenance and alternative routing are key factors in port resilience. Furthermore, Verschuur et al. [35] analyzed 141 port disruptions caused by natural disasters using vessel tracking data, revealing that the average disruption lasted six days and that operational recovery was more frequently implemented than port diversions. These studies demonstrate how data-driven approaches and optimization methods can enhance safety, resilience, and operational efficiency in the maritime transportation industry.

4.1.3. Cluster 3 (Dark Blue): Digital Transformation, Big Data, and Artificial Intelligence (AI) in the Maritime Industry

The integration of digital transformation, big data, and artificial intelligence (AI) in the maritime industry has significantly contributed to enhancing operational efficiency, navigational safety, and environmental sustainability. Aslam et al. [28] introduced the concept of the Internet of Ships (IoS), an IoT-based network that connects various maritime assets to improve automation and vessel efficiency. However, challenges remain in data security and information management, which require further advancements. Meanwhile, Yang et al. [29] demonstrated how big data derived from the Automatic Identification System (AIS) has revolutionized maritime navigation, enabling route optimization, global trade analysis, and environmental impact monitoring. In addition, Murray and Perera [27] developed a deep learning model based on AIS data to predict vessel behaviour and enhance early warning systems, thereby reducing the risk of maritime accidents. With ongoing advancements in IoT, big data analytics, and predictive technologies, the digitalization of maritime transportation continues to evolve, fostering a smarter, safer, and more sustainable maritime ecosystem.

4.1.4. Cluster 4 (Yellow): Risk Analysis, Navigational Safety, and Collision Mitigation Strategies in Maritime Transportation

Data-driven approaches and optimization algorithms play a crucial role in enhancing the efficiency and safety of maritime navigation. Goerlandt and Montewka [23] developed a Bayesian Network-based maritime risk analysis framework, which aids in assessing uncertainties within risk models and optimizing decision-making regarding potential accidents, such as oil spills caused by ship collisions. Meanwhile, Zhang et al. [24] introduced the Vessel Conflict Ranking Operator (VCRO), which utilizes Automatic Identification System (AIS) data to detect near-collision events by analyzing distance, relative speed, and vessel direction differences, thereby improving the effectiveness of navigational risk assessment. Furthermore, Zhen et al. [36] developed a real-time collision risk assessment framework based on DBSCAN clustering and risk indexing, enabling automatic risk detection and prioritization, enhancing maritime traffic monitoring, and supporting collision prevention strategies. By integrating AI, big data, and risk modelling, Cluster 4 highlights how modern technologies can optimize safety and efficiency in maritime transportation.

The following Table 3 presents the summary of the bibliographic coupling analysis with cluster number and colour, labels, number of publications, and representative publications.

Table 3.
Bibliographic coupling analysis on maritime transportation.

Cluster No and Colour	Cluster label	Number of Publications	Representative publication
1 (red)	Sustainability, Operational Optimization, and Technological Innovation in Maritime Transportation	14	Bouman, et al. [32]; Fagerholt, et al. [33] and Molavi, et al. [31].
2 (Green)	Risk Analysis, Operational Safety, and Maritime Transportation Resilience	11	Akyuz [34]; Baksh, et al. [25]; Hossain, et al. [26] and Verschuur, et al. [35].
3 (Dark Blue)	Digital Transformation, Big Data, and Artificial Intelligence (AI) in the Maritime Industry	11	Aslam, et al. [28]; Murray and Perera [27] and Yang, et al. [29].
4 (Yellow)	Risk Analysis, Navigational Safety, and Collision Mitigation Strategies in Maritime Transportation	9	Goerlandt and Montewka [22]; Goerlandt and Montewka [23] and Zhen, et al. [36].

4.2. Co-Word Analysis

Applying the same database, the co-word analysis presents 78 out of 20,137 keywords that met 58 thresholds, resulting in three clusters.

Table 4.
Top 15 keywords in the co-occurrence of keywords analysis.

Rank	Keyword	Occurrences	Total link strength
1	Maritime transportation	2365	7613
2	Ship	770	3808
3	Shipping	577	2439
4	Waterway transportation	565	2439
5	Risk assessment	310	1544
6	Port operation	318	1365
7	Vessel	227	1096
8	Decision making	228	1067
9	China	252	1066
10	Emission transport	170	909
11	Transportation planning	151	783
12	Maritime safety	133	773
13	Algorithm	145	759
14	Navigation	150	724
15	Numeric model	166	716

Figure 3 presents the network structure of the co-word analysis. It visibly shows three clusters representing three different themes. Following the author's inductive interpretation, the three clusters are assigned the appropriate labels.

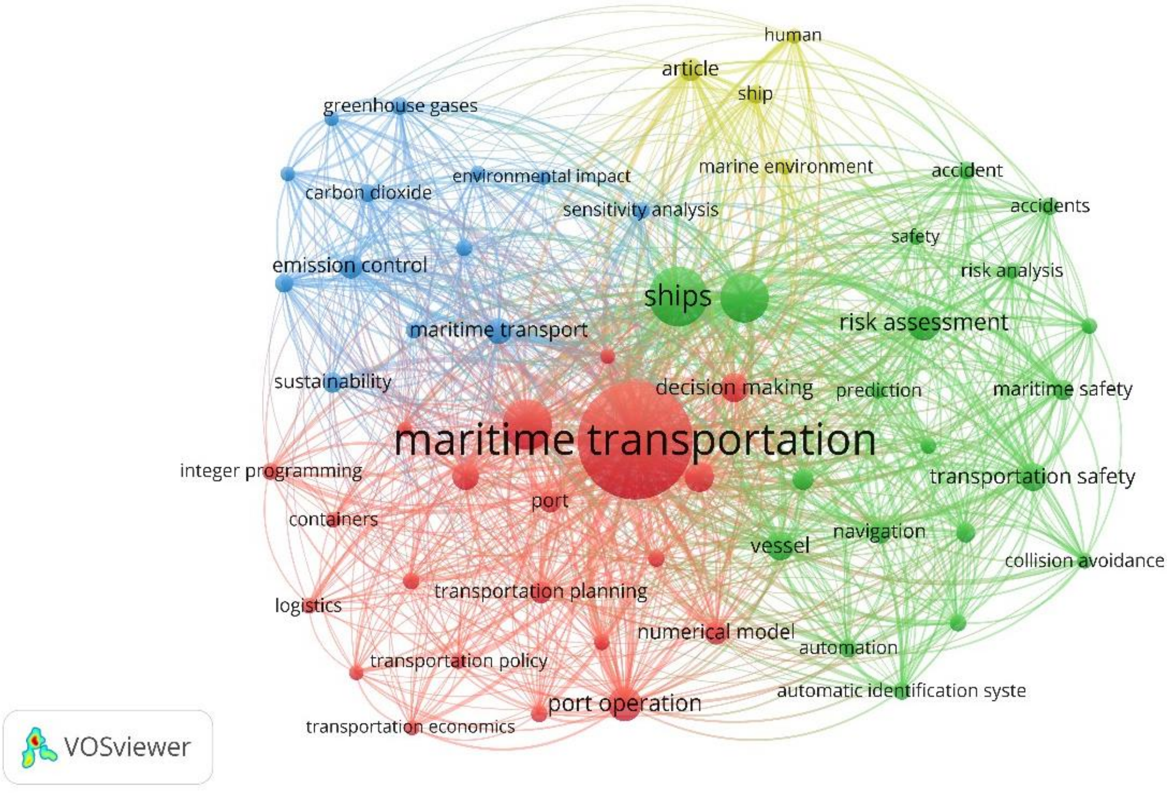

Figure 4.
Co-word analysis on maritime transportation.

4.2.1. Cluster 1 (Red): Maritime Transportation Optimization and Port Development in China

With 21 keywords, this cluster is labelled "Maritime Transportation Optimization and Port Development in China." The optimization of maritime transportation and port development in China involves the coordination of hinterland-port economies, sustainable development, logistics strategies, environmental policies, and technological advancements to enhance operational efficiency. A study by Gong et al. [37] demonstrated that the synergy between ports and hinterlands supports economic growth within the Maritime Silk Road initiative. Similarly, Wang et al. [38] analyzed 15 major ports in China, highlighting the importance of balancing operational capacity, economic conditions, and environmental factors for port sustainability. Chen [30] emphasized the need for maritime logistics optimization through resource integration and infrastructure investment to improve global competitiveness. Meanwhile, Zhou et al. [39] assessed China's green port policies, finding that while policies are well-designed, there remains a lack of coordination between central and local governments, and industrial incentives remain limited. To further improve efficiency, Jin et al. [40] applied artificial intelligence (GA-BP Neural Network) to predict maritime cargo volumes, aiding port managers in strategic planning and decision-making. Through these approaches, China continues to develop its ports into globally integrated, efficient, and sustainable transportation hubs.

4.2.2. Cluster 2 (Green): Machine Learning for Ship Risk Assessment and Waterway Optimization

With 20 keywords, this cluster is labelled "Machine Learning for Ship Risk Assessment and Waterway Optimization." The application of machine learning in ship risk assessment and waterway optimization has demonstrated significant potential in enhancing safety and efficiency in maritime transportation. Rawson et al. [41] compared conventional methods with machine learning approaches in maritime risk assessment, revealing that new algorithms can overcome the limitations of traditional methods. Similarly, Rawson et al. [41] implemented machine learning models to predict ship accidents based on maritime traffic data, incorporating variables such as vessel type, weather conditions, and navigation patterns. Meanwhile, Park and Jeong [42] employed a Relevance Vector Machine (RVM) to estimate collision risks, achieving higher prediction accuracy compared to traditional methods like Support Vector Machine (SVM). Lee et al. [43] developed machine learning strategies to predict safe berthing speeds, preventing accidents during port docking operations. Additionally, Lang et al. [44] applied the XGBoost algorithm to predict vessel speed and optimize voyage scheduling, enhancing route efficiency and reducing fuel consumption. Overall, these studies confirm that machine learning plays a crucial role in improving ship safety, minimizing accident risks, and optimizing navigation and maritime transportation management.

4.2.3. Cluster 3 (Blue): Sustainable Maritime Transport and Emission Control

With 13 keywords, this cluster is labelled "Sustainable Maritime Transport and Emission Control." The implementation of sustainable maritime transport strategies and emission control measures has become increasingly crucial in addressing environmental challenges and complying with global emission regulations. Sulik-Górecka and Strojek-Filus [45] emphasized the need for more harmonized standards in CO_2 emission reporting within the maritime transport sector to enhance transparency and the effectiveness of sustainability policies. Meanwhile, Wang et al. [38] explored the impact of emission trading policies in the European Union, revealing that speed optimization and fleet adjustments are key cost-mitigation strategies for shipping companies. Palaniappan and Vedachalam [46] highlighted that the transition towards eco-friendly maritime transport requires technological innovation, investment in alternative fuels such as hydrogen and ammonia, and the development of AI-driven autonomous vessels. Additionally, Borén et al. [47] demonstrated that slow steaming—reducing vessel speed—can significantly decrease fuel consumption and greenhouse gas emissions. However, they also noted that fuel consumption estimation methods must be refined for more accurate impact assessments. Furthermore, Schrooten et al. [48] developed a reference system for measuring and predicting ship emissions based on fleet characteristics, transportation activity, and energy consumption factors, providing a foundation for maritime emission mitigation policies. Overall, these studies affirm that effective emission control in the maritime sector requires a combination of robust regulatory policies, the adoption of environmentally friendly technologies, and data-driven operational strategies to achieve sustainable maritime transportation.

A summary of the co-word analysis is presented in Table 5, comprising cluster number and color, cluster labels, number of keywords, and representative keywords.

Table 5.
Summary of co-word analysis on maritime transportation.

Cluster No and color	Cluster label	Number of keywords	Representative Keywords
1 (red)	Maritime Transportation Optimization and Port Development in China	23	Maritime transportation, shipping, optimization, port
2 (green)	Machine Learning for Ship Risk Assessment and Waterway Optimization	20	Ships, Waterway Transportation, risk assessment, prediction, machine learning
3 (blue)	Sustainable Maritime Transport and Emission Control	13	Maritime transport, sustainable development, carbon emissions, emission control

5. Discussion

5.1. Digitalization of Maritime Transportation: Opportunities and Challenges

The digitalization of maritime transportation has emerged as a key trend in enhancing efficiency and sustainability within the industry. The adoption of technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data has led to significant transformations in maritime operations, improving safety, optimizing shipping routes, and enhancing fuel efficiency [13]. However, despite the vast opportunities offered by digitalization, several challenges remain, including system interoperability, cybersecurity risks, and infrastructure readiness, which continue to pose major obstacles to its implementation [49].

5.2. Digital Transformation in Maritime Transportation: Opportunities and Challenges

The digital transformation in maritime transportation presents significant opportunities to enhance logistics efficiency, reduce emissions, and improve supply chain transparency. Smart ports that adopt digital technologies can increase cargo handling speed and minimize ship queuing times, leading to greater operational efficiency and cost reduction [50]. Additionally, AI and Big Data enable navigation optimization by analyzing weather patterns and ocean currents to determine the most efficient routes [10]. However, despite these considerable benefits, the lack of technological standardization across countries and shipping companies remains a major challenge. Furthermore, cybersecurity threats pose significant risks, potentially disrupting maritime operations [51]. Ensuring data security and protection against information manipulation is crucial to sustaining digitalization efforts in the maritime sector.

Beyond technological aspects, regulatory frameworks and human resource readiness also pose significant challenges in the digitalization of maritime transportation. The lack of standardized regulations across different countries hinders the interoperability of digital systems between ports and vessels, thereby reducing the effectiveness of digital technology implementation [3]. Additionally, the shortage of a digitally skilled workforce remains a major obstacle to the adoption of AI- and Big Data-based systems [52]. Therefore, comprehensive training and education programs are essential to ensure the sustainability of digital transformation in the maritime transportation sector.

5.3. Sustainability in Maritime Transportation: Solutions and Strategies

Sustainability in maritime transportation has become a major concern amid increasing environmental regulations and the urgent need to reduce greenhouse gas emissions. One of the key solutions is the adoption of alternative fuels such as hydrogen, ammonia, and biofuels, which have a significantly lower environmental impact compared to conventional fuels [53]. Additionally, ship design optimization and route planning strategies are crucial factors in enhancing energy efficiency and reducing fuel consumption [54]. The implementation of digital technologies such as AI and Big Data in port operations and navigation management can further reduce carbon footprints by optimizing logistics distribution and minimizing vessel waiting times at ports [55].

Another strategy involves the implementation of IoT-based emission monitoring systems, enabling shipowners and regulators to identify and control emissions in real-time [56]. From a policy perspective, the introduction of carbon taxes and incentives for high-efficiency vessels can further encourage the adoption of environmentally friendly technologies [38]. Additionally, several countries have begun enforcing strict regulations on sulfur and nitrogen oxide emissions, aiming to mitigate the environmental impact of the shipping industry [57].

The development of green ports has emerged as a strategic initiative in achieving sustainable maritime transportation. This concept encompasses the use of renewable energy, electrification of port equipment, and enhanced operational efficiency through digitalization [58]. Ports that adopt cold ironing technology, which allows vessels to shut down their engines while docked and rely on shore-based electricity, can significantly reduce emissions [59]. Despite the numerous strategies proposed, the implementation of sustainability measures in maritime transportation continues to face challenges, including high costs and industry resistance to change [60]. Therefore, collaboration among governments, industries, and academia is essential to develop more effective and sustainable solutions.

6. Implications

6.1. Implications for Academia

The increasing digitalization and sustainability in maritime transportation present significant opportunities for academics to expand research in this field. Recent studies indicate that maritime transportation research trends have shifted from regulatory and policy aspects towards logistics optimization, operational efficiency, and environmental sustainability [1]. Academics play a strategic role in developing technology-driven solutions that enhance the efficiency and competitiveness of the maritime industry. One of the rapidly evolving areas is the application of Artificial Intelligence (AI) and data analytics in voyage route optimization, maritime supply chain management, and maritime trade pattern prediction [7].

Furthermore, academics play a crucial role in advancing maritime sustainability research, including decarbonization strategies and the transition to clean energy in the shipping industry [2]. With increasing regulatory pressure on carbon emissions, academic research can provide evidence-based insights into alternative technologies, such as the use of hydrogen and biofuels in maritime transportation. Additionally, research on ship design optimization strategies and fuel consumption reduction is essential to support the industry in meeting increasingly stringent environmental standards [6].

Academics can also contribute to enhancing maritime safety by developing machine learning-based predictive models to identify potential accident risks and improve navigational safety. Recent studies highlight that digitalization in vessel traffic monitoring can enhance collision response and port operational optimization [3]. Thus, academics play a crucial role in establishing more adaptive and technology-driven safety systems in the maritime industry.

Interdisciplinary and global collaboration is becoming increasingly important in addressing the complex challenges of the maritime industry. Partnerships between universities, research institutions, and the maritime sector can accelerate the development of evidence-based policies and the implementation of more efficient technological solutions [61]. Furthermore, academic research can contribute to the establishment of better international standards in maritime regulation and sustainability, as well as enhance the adoption of digital technologies in the global maritime industry [4]. Therefore, academics are not only responsible for expanding scientific knowledge but also for providing practical solutions to industry stakeholders and policymakers, ultimately enhancing the competitiveness and sustainability of global maritime transportation.

6.2. Implications for Industry

The maritime transportation industry faces significant challenges in adapting to the digital era and meeting global sustainability demands. One of the most influential aspects is digitalization, which can enhance operational efficiency and logistics transparency in the maritime sector. Recent studies indicate that the implementation of digital technologies, such as IoT, Artificial Intelligence (AI), and blockchain, in the maritime supply chain can optimize port management and increase industry competitiveness [13]. However, research also highlights that the adoption of digital technologies in the maritime sector remains lagging behind other industries due to regulatory constraints, high initial investment costs, and resistance to change [3].

Beyond digitalization, sustainability issues have become a key concern for the maritime transportation industry. Regulations from the International Maritime Organization (IMO) are placing increasing pressure on the industry to reduce carbon emissions, compelling maritime companies to adopt environmentally friendly technologies, such as alternative fuels and more efficient energy management systems [62]. With the growing demand for carbon footprint reduction, the maritime industry is expected to invest in energy-efficient ship designs and leverage digital solutions for real-time emission monitoring and reduction [59].

Maritime security has also become a critical aspect of the industry, particularly in addressing cyber threats targeting digital navigation and vessel management systems. As more vessels rely on satellite-based communication technologies and automation systems, the risk of cyberattacks on maritime systems has increased significantly [63].

Therefore, maritime companies must develop more robust cybersecurity systems and ensure compliance with global security standards to mitigate these risks effectively.

Additionally, the maritime transportation industry must enhance operational efficiency by implementing AI- and machine learning-based predictive maintenance systems. These technologies enable companies to identify potential failures in vessel systems before they occur, thereby reducing accident risks and lowering maintenance costs [64]. The implementation of AI-driven maintenance systems also contributes to sustainability by optimizing energy usage and minimizing operational waste.

Overall, the maritime transportation industry must adapt to technological advancements and global sustainability demands to remain competitive. Collaboration between industry stakeholders, governments, and academia is essential in developing evidence-based strategies to enhance efficiency, security, and sustainability in the sector [49]. With the right investments in digitalization, cybersecurity, and environmentally friendly technologies, the maritime industry can continue to grow and effectively address future challenges.

6.3. Implications for Policymakers

Policymakers play a crucial role in guiding the transformation of the maritime industry toward greater sustainability and efficiency. Well-designed regulations can encourage the adoption of environmentally friendly technologies, enhance safety, and strengthen the global competitiveness of the maritime sector. Studies indicate that one of the primary policy challenges in maritime governance is the tightening of greenhouse gas emission regulations by the International Maritime Organization (IMO), which compels governments to develop incentive policies supporting the industry's transition to low-carbon fuels such as hydrogen and electricity [58]. Additionally, digitalization policies in the maritime sector are becoming increasingly vital. The growing adoption of AI, blockchain, and IoT in the maritime supply chain necessitates new regulatory standards related to data security and system interoperability [4].

On the other hand, sustainable public procurement policies can serve as a strategic tool in promoting a more environmentally friendly maritime industry. Studies indicate that the implementation of Environmental Life-Cycle Costing (ELCC) in maritime procurement ensures that government-purchased vessels comply with higher environmental standards, thereby reducing the long-term environmental impact of maritime operations [65]. Moreover, policies that incorporate environmental externalities into operational costs can help create a fairer competitive landscape between fossil fuel-based technologies and green energy alternatives.

Policymakers must also consider risks in international maritime transport regulations, particularly concerning supply chain resilience and cybersecurity. Public policy risks in maritime transportation have become increasingly complex due to the global reliance on maritime trade routes, which remain vulnerable to political and economic disruptions. Therefore, a risk-based approach in maritime policy is essential to ensure the continuity of global logistics without compromising safety and efficiency standards [66]. Additionally, the implementation of risk mitigation policies through stronger international agreements can help reduce the impact of global instability on maritime trade.

Policymakers must ensure that maritime sector regulations strike a balance between economic needs and environmental sustainability. Studies indicate that overly stringent emission regulations can significantly increase operational costs and potentially hinder industry growth, whereas overly lenient policies may exacerbate maritime environmental degradation [67]. Therefore, an evidence-based approach is required to maintain a balance between economic growth and environmental protection in maritime policy development.

Overall, policymakers must adopt a holistic approach to maritime regulation design, integrating technological, economic, and sustainability considerations. Collaboration among governments, industry stakeholders, and academia is essential to ensure that policies are not only effective in reducing environmental impact but also support the economic growth of the maritime sector [1]. Thus, data-driven and research-based maritime policies can foster a more innovative, sustainable, and resilient industry, capable of addressing future global challenges.

7. Limitations and Future Opportunities

Despite rapid advancements in maritime transportation research, several limitations remain to be addressed. One of the key challenges is the limited availability of data sources used in academic studies. Most research relies on indexed scientific databases such as Scopus and Web of Science, which do not always include industry reports, government policies, and grey literature that may contain valuable insights into current maritime trends [6]. Additionally, bibliometric approaches, commonly used in maritime transportation trend analysis, have limitations in capturing the real-world impact of the reviewed research. Methods such as co-word analysis and citation analysis can illustrate academic relationships but do not necessarily reflect the practical contributions of a study to industry practices and public policy [1].

These limitations hinder industry stakeholders from directly adopting research findings, creating a gap between academic theory and real-world implementation [61].

Additionally, maritime transportation research continues to face challenges in integrating a broader multidisciplinary perspective. Many studies primarily focus on technical aspects, such as ship route optimization and port design, while few have explored the impacts of regulations, fiscal policies, and social engagement in the maritime industry in depth [66].

Moreover, research gaps remain in studies focusing on the digitalization of the maritime industry, particularly concerning cybersecurity and cross-sectoral data integration [4]. Emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and blockchain present significant opportunities for industry transformation. However, research on the regulatory frameworks and practical implementation of these technologies remains limited [3]. Therefore, future research should adopt a more interdisciplinary and collaborative approach, involving academics, industry stakeholders, and policymakers to develop practical and implementable solutions for the global maritime sector.

8. Conclusion

This study explores the developments and trends in maritime transportation research over the past decade using a bibliometric approach. By analyzing 3,286 documents from the Scopus database, this study identifies six key clusters through bibliographic analysis, reflecting various aspects of maritime transportation, including safety, sustainability, and operational efficiency. The bibliometric coupling analysis reveals that research in this field has increasingly focused on maritime transport risks, greenhouse gas emission reduction strategies, and the adoption of new technologies for navigational safety. Meanwhile, the co-word analysis identifies three main themes in the literature: maritime accident prediction, the growth of China's container trade, and sustainable maritime transportation strategies. This study has theoretical implications by enriching the understanding of the knowledge landscape in maritime transportation and practical implications for industry managers in adopting digital transformation and preparing for the Fourth Industrial Revolution. However, this study has certain limitations, such as its restricted scope to specific databases and the potential bias in keyword selection. Therefore, future research is recommended to expand data coverage and further explore the impact of regulations and emerging technologies on the maritime transportation industry.

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