

Maritime Transport Resilience: A Systematic Literature Review on the Current State of the Art, Research Agenda and Future Research Directions

Abstract

The maritime industry has faced unprecedented challenges resulting from climate change, epidemics, geopolitics and economic uncertainties, leading to the emergence of research on maritime transport resilience. However, key questions remain unresolved, particularly, what are the main contributions of the research community in the field of maritime transport resilience? Are the current trends of contributions focused on particular themes, geographical regions and directions? To address these questions, the study conducts a systematic review and bibliometric analysis of the current research trend, semantic patterns and the evolution of maritime transport resilience over the last two decades, based on a collection of 735 research papers exploring various topics in maritime transport resilience featured in key scholarly journals from 1997 to 2023. The research fosters the maritime transport research community to improve their self-understanding, promote interdisciplinary studies via fundamental collaboration and explore key research gaps to be addressed in the coming years.

Keywords: Maritime transport resilience; Bibliometric analysis; VOSviewer; Python; CiteSpace

1. Introduction

Containerisation, which standardised freight handling and facilitated efficient transfers, brought about a revolution in shipping during the 1950s. This innovation led to larger ships, scale economies and long-distance transportation (Levinson, 2006). International trade depends on maritime transport, in which over 90% of volumes are carried by vessels (Huang et al., 2022). Globalisation, multinational enterprises and trade agreements are all related to maritime expansion and promote the vast flow of products. Infrastructure and ports with specialised functions increase capacity, ease congestion and boost productivity. The maritime industry makes the transfer of energy resources, completed goods, and raw materials affordable and effective, benefitting various sectors, including manufacturing, agriculture, and mining. Between 1970 and 2022, the container shipping industry has seen significant cargo volume and fleet size growth. The deadweight tonnage of container ships grew from about 11 million metric tons in 1980 to roughly 293 million metric tons in 2022 (Statista, 2022). As of 2022, nearly 5,600 container ships were serving sea routes worldwide (Statista, 2022). Container vessels have become increasingly larger, capable of carrying higher loads, more fuel-efficient and faster. From 2011 to 2021, the share of container ships in the global commercial fleet increased from 4,966 to 5,534, with a nominal capacity of approximately 25 million TEUs (Marine Insight, 2021). Moreover, the container ship

fleet capacity and cargo carried have been increasing since 1970 (UNCTAD, 2022). The industry underwent significant growth in 2021, with a total of 561 container ships ordered, compared with 114 in 2020 and 107 in 2019 (Port de Barcelona, 2022). The data indicate that the container shipping industry has experienced significant growth in cargo volume and fleet size over the past few decades, with vessels becoming increasingly larger and more efficient.

Upon examining the data relating to the influence of the maritime shipping industry, this sector plays a significant role in generating economic growth, including GDP and employment rates. As of 2019, the total value of the world's annual shipping trade exceeded \$14 trillion (OECD, 2023). Shipping is responsible for almost 90% of global trade by volume, adding \$380 billion every year to the world economy via freight rates alone (ShipFinex, 2023). In addition, the maritime economy contributed about \$361 billion to the US GDP in 2020 (ShipFinex, 2023; NOAA, 2020). Shipping has developed highly sophisticated logistics chains, delivering just-in-time parts and goods to manufacturers and consumers (ShipFinex, 2023). These data indicate that the maritime shipping industry is critical to global trade and economic growth, contributing significantly to GDP and employment rates.

Although maritime transportation has advantages, it also has presents challenges. Environmental disruptions like oil spills and other hazardous discharges from vessels risk harming ecosystems and coastal communities. This necessitates proactive environmental protection initiatives and pollution prevention measures. The sector's greenhouse gas emissions are a factor in air pollution and climate change. For the purpose of lowering the carbon footprint, switching to cleaner fuels and implementing sustainable practices are essential. Safety and security are issues due to the potential of piracy and the unpredictability of the weather. For maritime transit to be safe and secure, monitoring needs to be improved, security needs to be put in place and international collaboration needs to be encouraged.

Overcapacity, changing freight rates and unstable fuel costs are a few issues affecting the marine transportation sector's economic viability and sustainability. Periods of oversupply in the sector can result in fierce rivalry and downward pressure on freight rates, which influence shipping businesses' profitability. Fuel price fluctuations can

considerably affect operational costs, making it difficult for businesses to maintain their financial stability. Sustainable business practices, market regulation, and strategic planning are required to solve these economic issues and guarantee the maritime transport sector's long-term existence.

Maritime transport resilience is crucial for addressing the issues and disadvantages specific to the sector. Environmental risks, such as potential oil spills and harmful discharges, necessitate strong environmental protection strategies and pollution prevention measures to protect ecosystems and coastal people. The industry may aid in decreasing air pollution and climate change by cutting greenhouse gas emissions, switching to cleaner fuels and implementing sustainable practices. Concerns about safety and security, such as piracy and unpredictability of the weather, highlight the necessity of improved surveillance, security measures and international cooperation. The sector's economic viability and sustainability are also threatened by overcapacity, fluctuating freight rates and uncertain fuel prices. Overcoming these economic obstacles and ensuring financial stability requires the adoption of sustainable business practices, the establishment of market regulations and strategic planning. The maritime industry may grow and help create a sustainable and prosperous future by encouraging resilience in all areas of environmental, safety and economic concerns.

Assessing the maritime transport research paper is essential for improving our knowledge of this topic and identifying any gaps or potential study areas. Conducting a study in this area is significant for a number of reasons, including the fact that maritime transit is a crucial part of global connectivity and trade. Firstly, it enables us to evaluate the present level of knowledge and determine current research trends, methodologies and conclusions. This assessment offers a thorough picture of the research environment, allowing academics, decision-makers and business leaders to build on prior knowledge and reduce duplication of effort. Secondly, it highlights maritime transportation's difficulties and detrimental effects, such as environmental pollution, safety hazards and financial instability. Understanding them is essential to design efficient methods, policies, and technology to solve these difficulties. In addition, the review of the study article explores ways to strengthen maritime transport networks' resilience so they can endure and recover from interruptions. This analysis drives the need for further research by highlighting the gaps in the existing body of knowledge,

allowing scientists to concentrate on important topics and aid in the creation of robust and sustainable maritime transport networks. In the end, this study is crucial in maintaining maritime transport's effectiveness, safety and environmental sustainability, encouraging international seaborne trade and promoting economic progress.

The outbreak of the COVID-19 pandemic initially emerged in late 2019 and rapidly spread around the globe, stimulating concerns about the humanitarian, supply chain, and economic aspects (Lau et al., 2020). Due to the COVID-19 pandemic, maritime transport has changed exceptionally, which has induced shipment delays, rising freight rates, supply chain disturbance, and intensified port congestion. In addition, the Suez Canal was blocked for 6 days by a 20,000 TEU container vessel named Ever Given in March 2021, resulting in financial losses amounting to hundreds of millions of dollars (Fan et al., 2022). The maritime transport system has become increasingly vulnerable to various threats due to the continuous interconnectivity between nations worldwide. Any disruptive or emergency incident can seriously affect human beings and industries, focusing on the significance of maritime transport resilience (Panahi et al., 2022). In response, the systematic review approach employed in 'Maritime Transport Resilience: A Systematic Literature Review on the Current State of Art, Research Agenda, and Future Research Directions' is a crucial selling point of the study. The systematic review methodology ensures a rigorous and comprehensive analysis of the existing literature, providing a robust foundation for understanding the current state of knowledge in the field of maritime transport resilience. By systematically searching, selecting and synthesising relevant studies, this approach minimises bias and enhances the reliability and validity of the findings. It allows for the identification of key research trends, methodologies and gaps, offering valuable insights to researchers, policymakers and industry professionals. Moreover, the systematic review approach provides a clear research agenda and future research directions, guiding future investigations and enabling the field to progress in a targeted and informed manner. The systematic review approach employed in this study enhances its credibility, ensuring that the findings and recommendations are based on a comprehensive and robust analysis of the existing literature, making it an essential contribution to the field of maritime transport resilience.

The term 'resilience' is commonly adopted to describe the capacity of the system to return its routine operations and recover from a disruptive incident. Resilience

originated from the Latin *resiliere* (Besinovic, 2020). Collins Concise Dictionary (1978) describes resilience as ‘springing back into shape, position, etc. after being stretched, bent or compressed’. As such, resilience implies its capacity to enhance, return or maintain its original functions and performance (Wan et al., 2018). It was initially advocated by Holling (1973) in ecological systems. Afterwards, the concept of resilience has been extensively expanded into various scientific ways and other disciplines, such as supply chain management; communities, economics, social, organisational and critical infrastructure; psychology, engineering, transport, energy and ecology, to name a few (Mattsson and Jenelius, 2015; Cheng et al., 2022). Wang (2015) claimed that the idea of resilience is expected to be highly extensive, containing the reliability of daily fluctuations in capacity and demand, recovery from disasters and sustainability of the transport system in response to continuing changes, such as climate change. Although past research has inclined towards maritime transport resilience, studies have mainly addressed maritime network resiliency (Chen et al., 2018), transport system resiliency (Zhou et al., 2019), freight transportation system (Akpınar and Ozer-Caylan, 2023), resilience capacity in shipping firms (Yang and Hsu, 2018) and port resilience (Panahi et al., 2022). We identify maritime transport resilience as the maritime transport industry practitioners or stakeholders that may restart an ideal performance level and endure disturbance after disruptive incidents. Maritime transportation resilience is a current topic and a challenge for maritime transportation agencies (Allen et al., 2023). However, the main questions remain unresolved. Specifically, what are the main contributions by the research community in the field of maritime transport resilience? Are the current trends of contributions focused on particular themes, geographical regions and directions? In doing so, this paper investigates the current research trends and the evolution of maritime transport resilience through bibliometric analysis and a systematic review of the literature in this area.

We employ bibliometric analysis to summarise the currently published research papers on maritime transport resilience from 1997 to 2023. The academic and practical contributions of this study are as follows. Firstly, our study examines maritime transport resilience articles adopting bibliometric analysis, cluster analysis, co-word analysis and various excellent data analysis tools. Through this, it identifies clusters, academic institutions, journals, authorship patterns, countries and keywords. Secondly, we use

CiteSpace to foster researchers in discerning significant patterns in maritime transport resilience publications and in identifying the notable features of scientific information. Thirdly, our research offers potential future research directions for subsequent studies. This guidance is poised to aid researchers, policymakers and industrial practitioners in shaping their future research.

Based on the literature, maritime transport resilience in this research is defined as the ability of the maritime sector to anticipate, prepare for, respond to, and recover from disruptions, encompassing environmental, safety, economic, and systemic dimensions. This resilience is crucial for the sector's contribution to global connectivity, trade, and sustainable development. Then, to evaluate maritime transport resilience, this paper is divided into four main sections. Section 1 introduces the research background, settings and objectives. Next, Section 2 mainly describes the research methodology and examines selected articles. Then, Section 3 discusses and investigates the results. Finally, the conclusion is summarised in Section 4.

2. Methodology

2.1 Bibliometric Analysis

Bibliometrics is a burgeoning, interdisciplinary field that integrates linguistics, mathematics and statistics. Its analysis tracks research evolution and identifies relevant trends in various areas. This method is commonly used to explore the development of academic research disciplines, recognise current research hotspots and predict future research trends. To this end, the main objectives of this research are to (1) broaden scholars' perspectives on the landscape and scope of research focused on maritime transport resilience through the bibliometric analysis of research papers published in the Web of Science Core Collection database, especially emerging and understudied themes; and (2) lay the groundwork for future research directions for maritime industry practitioners or stakeholders in the area of maritime transport resilience.

To comprehensively identify the relationship between maritime transport and resilience, this paper uses data analysis tools, such as VOSviewer, Python and CiteSpace, to comprehensively sort out the relevant Web of Science literature. This part takes the Web of Science as the data source and selects the core collection in the Web of Science database as the retrieval object. The search conditions are set as follows: the subject is

‘Port’ and ‘Resilience’ OR ‘Maritime’ and ‘Resilience’ OR ‘Shipping’ and ‘Resilience’ OR ‘Ship’ and ‘Resilience’ OR ‘Water Transport’ and ‘Resilience’ OR ‘Container’ and ‘Resilience’; and the period is from 1997 to 2023 (see Table 1). The search results are de-duplicated and sorted to recognise the relevant literature (Yu et al., 2023). As of March 20, 2023, the number of valid articles included in the research is 735.

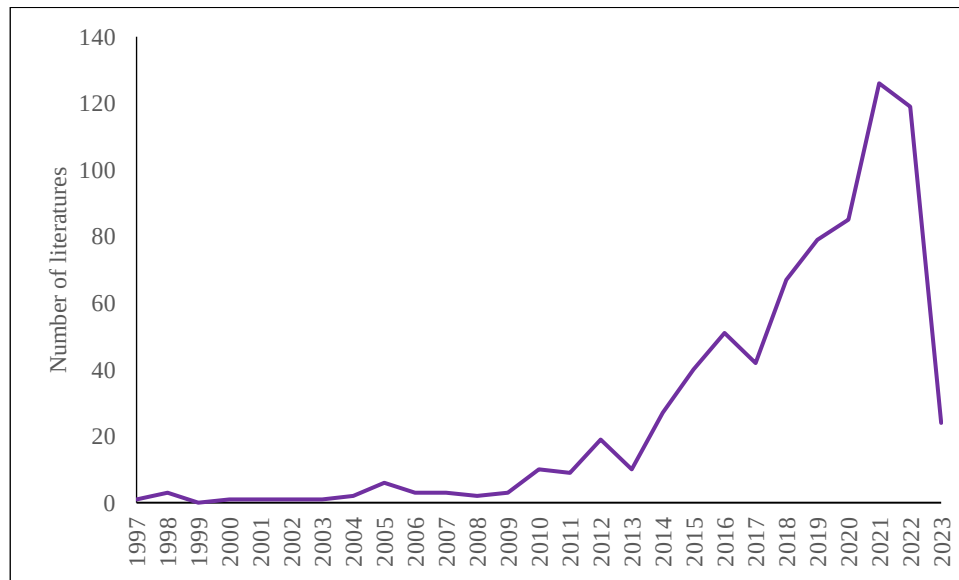


Figure 1. Number of Literature Articles

The development of maritime transport resilience in 27 years can be obtained through the number of publications in different years. Figure 1 shows that the number of research papers in this area can be divided into two main stages. The first stage was from 1997 to 2009, and a total of 27 papers were published, with an average of 2 papers per year, accounting for 3.67% of the total number of papers. The second stage is after 2010, and a total of 708 papers were published, with an average of about 50 papers published each year, accounting for 96.32% of the total number of papers. The number of published papers is increasing exponentially, as shown in Table 3. Mainstream maritime journals have published numerous articles on maritime transport resilience, such as sustainability, ocean and coastal management, reliability engineering and system safety, marine policy and maritime policy and management. These journals have published 37.7% of the articles on maritime transport resilience. Research papers relevant to maritime transport resilience have dramatically increased since 2019. The rationale behind this is the outbreak of the COVID-19 pandemic induced the unfolded challenges in the maritime industry. In addition, events such as the Suez Canal blockage,

recent natural disasters, US–China trade conflicts and geopolitical repercussions of the Russia–Ukraine war have all led to port congestion, increased freight rates, interference of maritime transport and shipment suspension; these events have generated the urgency of maritime transport resilience research (Twumaski-Boakye and Sobanjo, 2021; Yu et al., 2023).

2.2 Analysis of Authors and Countries

The co-occurrence network can provide a useful reference for evaluating academic influence and discovering scholars worthy of attention. The size of network nodes reflects the number of articles published by the author, and the links indicate the internal relationship between them. The core author group and their cooperative relationships in this field can be determined by analysing the structural characteristics of authors and their cooperative networks. According to the archive documents, this study uses VOSviewer software. By imposing constraints on node connections (the minimum number of author appearances is 2, and a minimum of one collaboration with another author), we have identified a total of 192 authors who meet these conditions. We obtained the literature between the authors' connection diagram, as shown in Figure 2. From the figure, Yang ZL and Becker A have conducted numerous studies in this field. In addition, abundant collaborations amongst scholars are observed, with each scholar forming his research team to delve into specific research fields. However, the connection between scientific research teams is weak, and academic exchanges are few. As for the countries that published articles in this area (see Figure 3), scholars from the US published the most articles, followed by countries China (People's Republic of China) and the UK (England). Figure 3 shows a relatively frequent collaboration between domestic and foreign countries.

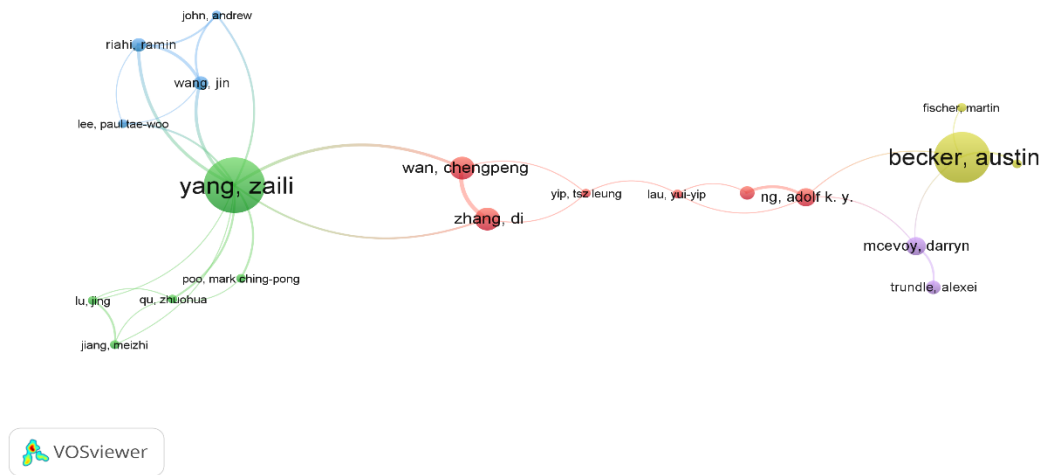


Figure 2. Map of Authors

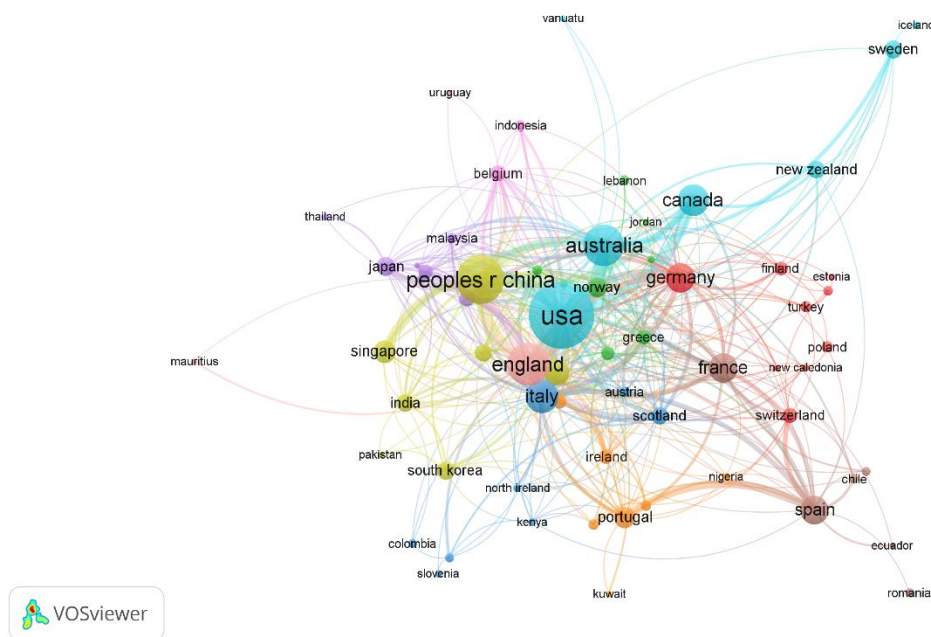


Figure 3. Map of Countries of Authors

2.3 Analysis of Academic Institutions

According to the data analysis results, Python is used to examine the academic institution of the literature. Table 1 presents the top 10 academic institutions for research related to maritime transport resilience. Dalian Maritime University published the most articles (23 articles), followed by Griffith University, Nanyang Technology University and Liverpool John Moores University. Generally, the unique feature of the

aforementioned academic institutions cultivates a strong research culture, with renowned researchers at the leading academic research. Researchers are energetic, self-driven and goal-oriented. They concentrate on worldwide topics and relevant policies, investigate main problems that require clarification, and give substantial energy and time to complicated research processes. Furthermore, these institutions are mainly maritime colleges and universities, and they considerably influence maritime affairs. The cities where the schools are located have important ports for import and export trades.

Table 1. Top 10 Academic Institutions for Research Related to Maritime Transport Resilience

Name of Academic Institutions	Number of Journals
Dalian Maritime University	23
Griffith University	21
Nanyang Technol University	17
Liverpool John Moores University	16
Chinese Academy of Science	15
University of Southern California	15
University Medicine Greifswald	15
University of Maryland	14
University of Rhode Island	14
Stanford University	13

2.4 Analysis of Keywords

The distribution and evolution of keywords can intuitively reflect the research hotspots in different periods and the changes in analytical perspectives and research methods. Keywords are a high-level summary of a document. All keywords related to maritime transport resilience are summarised in Table 2. Keyword analysis can reflect the current research status and trends in this field. Figure 4 shows the collinear map of keywords. The size of keywords corresponds to the frequency of keyword occurrences. Larger fonts indicate more times of occurrence. The keywords with higher frequency are resilience, analysis, COVID-19, sustainability, management, security, development, adaptation, assessment and vulnerability. As such, we summarise the analysis of cited journal keywords in the literature in Figure 5 and Table 3.

Table 2. All Keywords Related to Maritime Transport Resilience

Keyword	Total
Resilience	59
Analysis	9
COVID-19	5
Sustainability	9
Management	5
Security	5
Development	4
Adaptation	4
Assessment	4
Vulnerability	7
Systems	3
Stochastic programming	5
Network	3
System	3
Sustainable development	3
Hydraulic traits	3
Variability	3
Maritime pine	5
Tsunami	3
Climate change	3
Change	3
Planning	3
Northern Sea Route	2
Recovery	2
China	2
Investment	2
Evidential reasoning	2
Simulation	2
Maritime transport	4
Preparedness	2
Vessels	2

Protocols	2
Modelling	2
Maritime	2
Recovery	2
Maritime safety	2
Port	2
Learning	2
Effects	2
Reforestation	2
Transport	2
Machine learning	2
Study	2
Cyber-physical systems	2
Maritime risk	2
AIS data	2
Evaluation	2
Bayesian network	2
Port disruptions	2
Networks	2
Resilience engineering	2
Cybersecurity	2
Structural equation modelling	2
Quercus suber	2
Reliability	2
Transportation	2
Safety	2
Coherence	2
Knowledge	2
Maine	2
Regional	2
Pinus pinaster	2
Leaf anatomy	2
Protected areas	2

Disaster management	2
Climate change	2
Infrastructure	2
Engineering	2
Industry	2
Marine spatial planning	2
Resistance	2
Traditional knowledge	2
Heritage	2
Refugia	2
School	2
Fisheries	2
Arctic	2
Europe	2
Strategies	2
Seaports	5
Earthquake	2
Liquefaction	2
Response	2
Community resilience	2
Urban resilience	2
Tasmanica	2
Events	2
Mitigation	2
Benthic communities	2
Robustness	2
Detection	2
System resilience	2
Optimisation	2

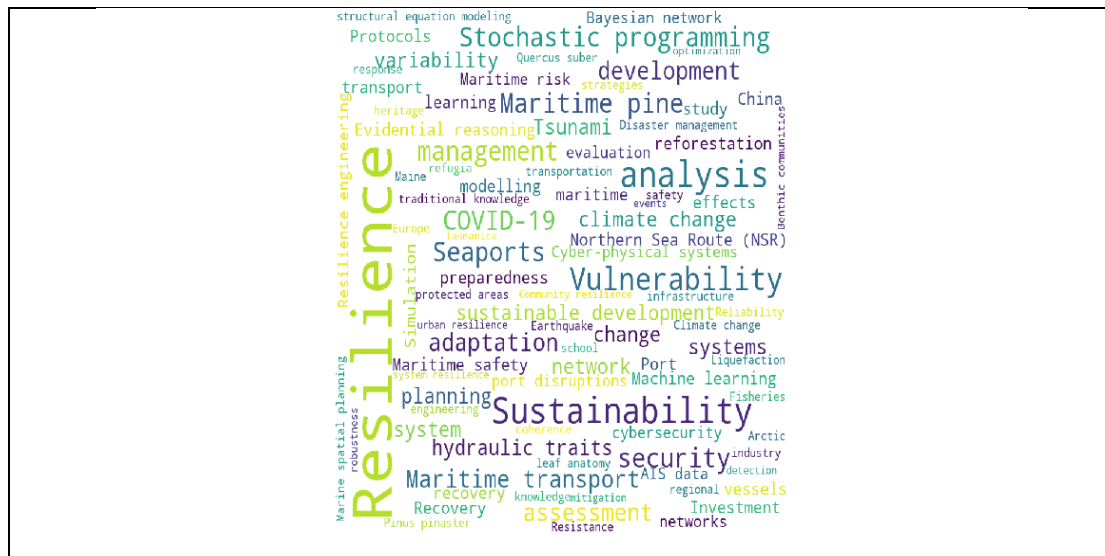


Figure 4. Co-occurrence Map of Keywords in the Literature

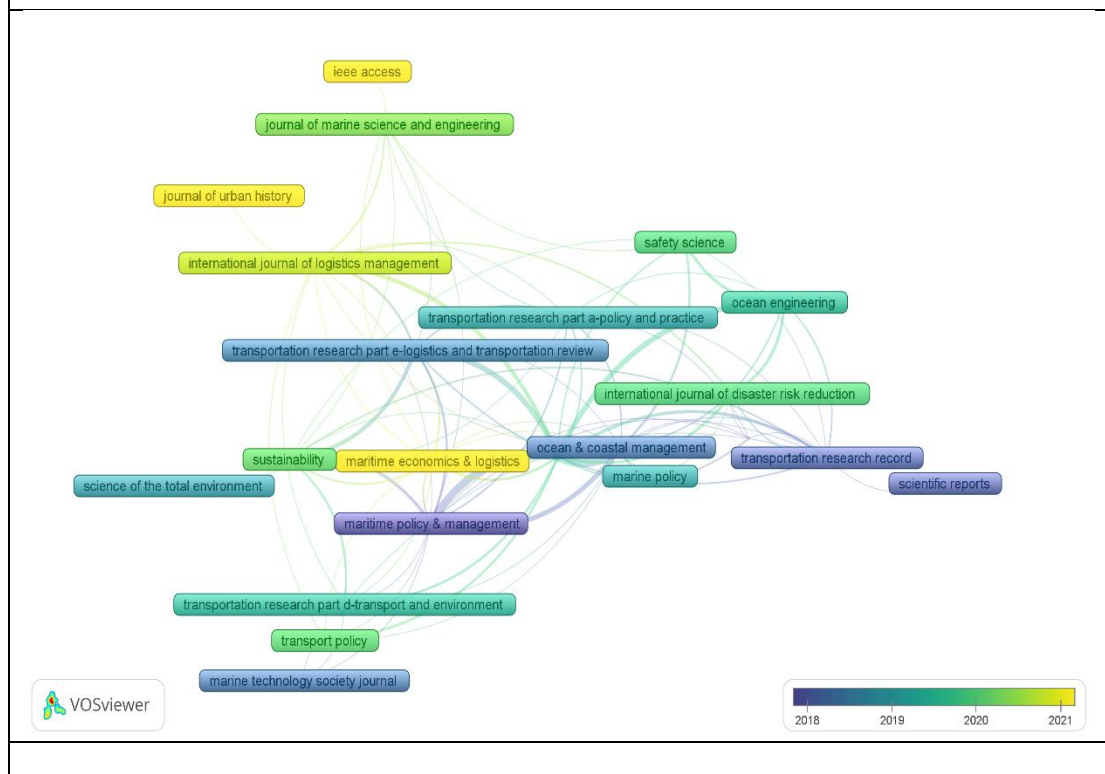


Figure 5. Analysis of Cited Journal Keywords in the Literature

Table 3. Analysis of Cited Journal Keywords in the Literature

Name of Journal	Number of Articles	Citations	Total Link Strength
Ecology and Society	5	70	0
IEEE Access	7	45	1
International Journal of Disaster Risk	12	190	14

Reduction			
International Journal of Logistics Management	6	26	19
Journal of Marine Science and Engineering	10	103	9
Journal of Urban History	9	27	1
Marine Policy	16	165	4
Marine Pollution Bulletin	5	99	1
Marine Technology Society Journal	5	20	3
Maritime Economics and Logistics	6	111	15
Maritime Policy and Management	13	209	34
Natural Hazards	6	102	7
Ocean and Coastal Management	20	285	34
Ocean Engineering	6	106	20
PLoS One	9	106	1
Reliability Engineering and System Safety	20	609	63
Safety Science	12	236	12
Science of the Total Environment	8	139	1
Scientific Reports	7	393	1
Sustainability	26	215	21
Transport Policy	5	78	8
Transportation Research Part A: Policy and Practice	7	160	14
Transportation Research Part D: Transport and Environment	5	103	12
Transportation Research Part E: Logistics and Transportation Review	5	198	26
Transportation Research Record	11	109	19
Tree Physiology	5	34	0
Water	6	6	0

2.5 Literature Cluster Analysis

This study employs CiteSpace to analyse the literature clustering, as shown in Figure 6. The significance of cluster analysis in research is multifaceted and profound by grouping similar studies, identifying research trends and then revealing research gaps (Danese et al., 2028).

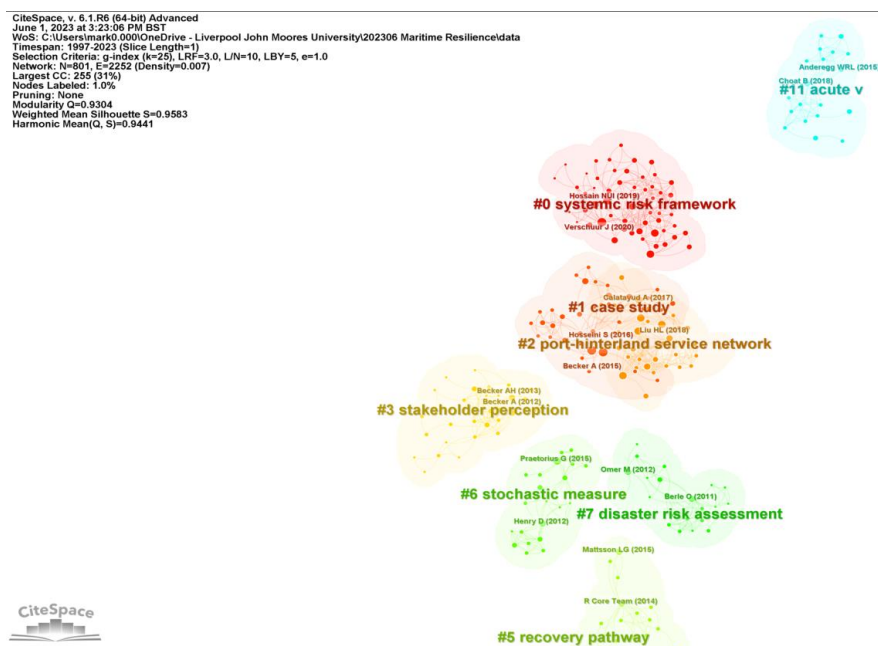


Figure 6. Literature Cluster Analysis

Cluster 0 has 60 members and a silhouette value of 0.945. The cluster highlights the importance of understanding and managing systemic risks in the context of port resilience. It also emphasises the need for a comprehensive approach that considers various factors, adaptation mechanisms, empirical insights and system-wide measures to improve the resilience of port and supply chain networks. By incorporating these insights into risk assessment and decision-making processes, stakeholders can work towards creating highly robust and adaptive systems in the face of various risks and disruptions.

Cluster 1 has 39 members and a silhouette value of 0.921. This cluster focuses on understanding interdependencies, evaluating resilience, engaging stakeholders and sharing information to enhance system resilience in ports and supply chains. By considering these factors and adopting a holistic approach, stakeholders can effectively assess vulnerabilities, prioritise strategies and collaborate to build highly resilient and adaptive systems.

Cluster 2 has 35 members and a silhouette value of 0.935. This cluster points out the significance of studying and analysing various aspects of resilience and vulnerability in different port and supply chain network contexts. The research presented in these studies contributes to understanding risk factors, interdependencies, control strategies and the effects of disruptions on the overall network. Analytical frameworks, such as Bayesian networks and multi-centrality models, enable the identification of vulnerabilities and the development of resilience-building strategies. The findings provide valuable insights for practitioners and decision makers in designing highly robust and resilient port and supply chain systems to mitigate the effects of disruptions

and enhance overall performance.

Cluster 3 has 31 members and a silhouette value of 0.985. These papers indicate the implication of addressing the effect of climate change on seaports and highlight the need for proactive measures to enhance seaport resilience. In addition, they underscore the value of stakeholder engagement, knowledge exchange, holistic planning and integration of climate-related factors into decision-making processes. By adopting inclusive approaches, increasing awareness, fostering collaboration and considering climate change in infrastructure planning and resource management, seaports can enhance their ability to withstand the influence of climate change, protect critical infrastructure and contribute to sustainable global trade.

Cluster 5 has 24 members and a silhouette value of 0.994. Collectively, these papers focus on addressing the effect of climate change on seaports and highlight the need for proactive measures to enhance seaport resilience. They underscore the value of stakeholder engagement, knowledge exchange, holistic planning and integration of climate-related factors into decision-making processes. By adopting inclusive approaches, increasing awareness, fostering collaboration, and considering climate change in infrastructure planning and resource management, seaports can enhance their ability to withstand the effect of climate change, protect critical infrastructure and contribute to sustainable global trade.

Cluster 6 has 23 members and a silhouette value of 0.983. Collectively, these studies enhance our understanding of resilience in port operations and infrastructure networks. These studies offer valuable approaches to quantify and analyse resilience, inform decision-making processes and improve port systems' overall performance and adaptability by utilising empirical data, analytical techniques and stakeholder insights. The findings contribute to building highly resilient and sustainable transportation and infrastructure networks.

Cluster 7 has 23 members and a silhouette value of 0.959. These studies provide valuable insights into assessing and enhancing the resilience of maritime transportation systems and freight networks. By considering vulnerability, risk assessment, resiliency metrics and optimal preparedness and recovery actions, these studies contribute to developing strategies and frameworks that enable effective response and adaptation to disruptions. The findings support the sustainable and robust operation of transportation systems in the face of evolving challenges.

After analysing the various clusters and studies in maritime transport resilience, it becomes evident that while significant strides have been made in understanding and enhancing the resilience of maritime transport systems, there remain critical gaps that future research needs to address.

The studies collectively highlight the complexity of resilience in maritime transport, encompassing systemic risks, climate change impacts, and operational and infrastructural resilience. However, an integrated approach that combines these diverse aspects is still lacking. For instance, while Cluster 0 and Cluster 1 emphasise systemic risks and interdependencies in port resilience, there is a need for research that bridges these systemic insights with the operational tactics discussed in Cluster 6 and the climate change adaptation strategies in Clusters 3 and 5. This indicates a gap in

comprehensive, multi-faceted research that holistically addresses maritime resilience.

3. Results and Discussions

3.1 Resilience of Maritime Transport Systems and Freight Networks

The study provides valuable insights into assessing and enhancing the resilience of maritime transportation systems and freight networks. Hsieh (2014) focused on assessing the risk of port failures from a vulnerability perspective. He evaluated vulnerable factors using geographic information systems and assessed the risks associated with port operations. This study provided insights into quantifying the vulnerability and risk of port failures, offering valuable information for decision makers to develop strategies and minimise disaster risks in ports. Omer et al. (2012) proposed a framework for assessing the resiliency of maritime transportation systems. They presented schemes to improve resiliency by reducing vulnerability and increasing adaptive capacity. Resiliency metrics were evaluated using a networked infrastructure resiliency assessment framework. This research offered a comprehensive framework for evaluating and improving the resiliency of maritime transportation systems, facilitating effective decision making to minimise socioeconomic effects during disruptions.

Berle et al. (2011) introduced a formal vulnerability assessment methodology for maritime transportation systems. They adopted the formal safety assessment framework to assess the ability of transportation systems to serve as throughput mechanisms of goods and recover from disruptive events. This methodology provided a structured approach to assess vulnerabilities and enhance the ability of maritime transportation systems to cope with unforeseen threats and hazards, contributing to supply chain resilience. Miller-Hooks et al. (2012) addressed measuring and maximising resilience in freight transportation networks. They formulated a problem as a two-stage stochastic program, considering the network's coping ability and the optimal set of preparedness and recovery actions. Their research offered a methodological approach to measure and maximise the resilience of freight transportation networks, allowing for informed decision making and allocation of resources to enhance network performance during disruptions.

3.2 Resilience of Ports and Supply Chains

This study highlights the importance of understanding interdependencies, evaluating resilience, engaging stakeholders and sharing information to enhance system resilience in ports and supply chains. Hossain et al. (2020) examined in a case study the interdependencies between an inland waterway port and its surrounding supply chain network. They quantified the interconnectedness of various factors related to port disruption and supply chain performance by utilising a Bayesian network. The emphasis on environmental factors and supplier responsiveness underscores the need to consider multiple dimensions when assessing and enhancing system resilience. This case study provided valuable insights into the complex relationships within the port and its supply chain, enabling stakeholders to prioritise strategies for improving the overall resilience. Hosseini et al. (2016) reviewed system resilience definitions and measures, focusing on engineering systems. The review addressed the various approaches to measure resilience and highlighted gaps and challenges in the current literature. This overview is valuable for researchers and practitioners seeking to assess and enhance resilience in diverse contexts. Identifying gaps and challenges also directs future

research efforts towards developing highly robust and standardised methods for evaluating resilience. The case study by Becker and Caldwell (2015) explored stakeholder perceptions of seaport resilience strategies through empirical data gathered from two US ports. The study concentrated on engaging various stakeholders in resilience planning and identifying feasible strategies for enhancing port resilience. By considering the roles and perspectives of different stakeholders, the research highlighted the significance of collaboration and collective action in addressing the challenges posed by climate change and other disruptive factors. This case study offered practical insights for port planners and external stakeholders involved in resilience enhancement. Shaw et al. (2017) investigated multi-level port resilience planning in the UK, focusing on information sharing amongst port stakeholders. The study recognised the complexity and interdependencies within port systems and proposed an approach to information sharing that considers stakeholders' confidentiality, political sensitivity and diverse perspectives. By addressing barriers to information sharing, this case study offered valuable insights into fostering collaboration and facilitating effective resilience planning in port systems. Furthermore, the proposed approach constructed a foundation for improved stakeholder communication and coordination, enabling a comprehensive and integrated approach to port resilience.

This study highlights the importance of studying and examining various aspects of resilience and vulnerability in different port and supply chain network contexts. Kuang et al. (2021) focused on the stability analysis and control strategy for the chained propagation of delay or disruption risks in a port-hinterland service network (PHSN). They constructed a model that analyses risk factors and risk-generating paths using the fuzzy analytic hierarchy process framework. The stability analysis assesses the elasticity of carriers and ports to infected nodes in the hinterlands, infection rate and recovery rate to obtain an optimal control strategy. The results showed that external factors causing delay or disruption risk are more important than internal factors, and increasing the recovery rate is the most effective control measure. This study provided valuable insights into risk control in PHSNs. Liu et al. (2018) aimed to analyse vulnerabilities in maritime supply chains and develop a framework to identify and analyse these vulnerabilities. A case study of the Maersk shipping line in the Asia–Europe route was conducted to demonstrate the framework's applicability. The authors investigated robustness against random failures and deliberate attacks in the network. Vulnerable nodes (ports) were identified using multi-centrality and robustness analysis models. The similarities and differences between the two analyses provide insights into vulnerable nodes against different threats. The results aid in designing and operating resilient and robust maritime supply chains. From a multiplex network perspective, Calatayud et al. (2017) explored the vulnerability of international freight flows to disruptions in maritime transportation services. Network modelling and simulation of attacks on strategic nodes were conducted to analyse the vulnerability of freight flows based on the country of origin and the country's role in the maritime transportation network. The study highlighted the varying levels of vulnerability across different countries and the effect of the complex structure of liner shipping networks on freight flow risks. Hosseini and Barker (2016) introduced a Bayesian network approach to model infrastructure resilience, focusing on inland waterway ports as a case study. They quantified resilience through absorptive, adaptive and restorative capacities and used Bayesian networks for resilience analysis and evaluation. The forward and backward propagation techniques facilitated the analysis of different resilience-building strategies. The authors demonstrated the adoption of Bayesian networks in quantifying resilience,

providing insights for enhancing the resilience of inland waterway ports and the wider intermodal transportation network.

3.3 Effect of Climate Change on Port Resilience

This paper emphasises the importance of addressing the effect of climate change on seaports and highlights the need for proactive measures to enhance seaport resilience. Becker et al. (2015) highlighted the significance of incorporating stakeholder perceptions and concerns in the planning and policy-making processes for seaport resilience to the effect of climate change. They addressed the need for inclusive and participatory approaches that highlight the extensive effects of hurricanes on ports and the costs borne by stakeholders and society. Their study revealed a gap between stakeholder concerns and their inclusion in resilience planning, suggesting the need to integrate stakeholder perspectives to develop effective strategies. Becker et al. (2012) examined the knowledge and perceptions of port administrators regarding the effect of climate change on seaports. Their study focused on the vulnerability of seaports to climate-related hazards and the need for increased awareness amongst port administrators. It highlighted the importance of bridging the gap between scientific knowledge and port administrators' understanding of the effect of climate change to facilitate the integration of adaptation measures into seaport planning and operations. Becker et al. (2013) underscored the challenges and implications of climate change for seaports in global trade and development. They identified the vulnerability of seaports to extreme weather events and rising sea levels, reflecting the need for collaborative efforts and holistic planning approaches. They also called for a shift towards comprehensive planning, investment and operation strategies to enhance seaport resilience and contribute to sustainable trade. Becker et al. (2016) suggested a method to estimate the demand for construction materials necessary to protect seaports from sea-level-rise-enhanced storm surges. The study introduced the concept of a minimum assumption credible design that leverages local information and engineering knowledge to forecast resource demand. It highlighted the significance of climate-related factors in infrastructure design and construction and emphasised the need to consider climate change into resource planning to enhance seaport resilience.

The present paper also highlights the importance of addressing the effect of climate change impacts on seaports and the need for proactive measures to enhance seaport resilience. Smith et al. (2016) examined the recovery pathways of the seagrass *Zostera nigricaulis* in Port Phillip Bay, Australia, following small-scale disturbances. The research investigated whether these pathways differ between regions with different hydrodynamic conditions and water quality and between local sites. The authors found that the recovery pathways were generally consistent across regions, but substantial differences existed between local sites. Recovery time varied depending on the extent of biomass removal, with no evidence of recovery through sexual reproduction. The study highlighted the importance of understanding fine-scale variation in local recovery mechanisms. The first highly cited article is related to the R code. Secondly, Mattsson and Jenelius (2015) provided an overview of recent research on vulnerability and resilience in transport systems. They distinguished two traditions in transport vulnerability studies: one focusing on network topology and the other incorporating demand and supply considerations. Thirdly, resilience was introduced as a broader perspective on the transport system's capacity to maintain or recover its function after disruptions or disasters. The authors argued for more cross-disciplinary collaborations to translate research findings into practical strategies for enhancing transport system

resilience. Ball et al. (2014) focused on historical seagrass mapping in Port Phillip Bay, Australia, using aerial photographs from 1939 to 2011. The research identified changes in seagrass cover and explored possible influences on these changes. The study revealed significant declines in seagrass cover after 1998, following a period of expansion from the 1960s to the 1990s. The declines were not consistent throughout the bay, suggesting the importance of variations in weather patterns and sediment transport as determining factors.

These papers collectively underline the growing concern about the impacts of climate change on maritime transport systems, particularly seaports. They emphasise the need for comprehensive planning, stakeholder involvement, awareness among port administrators, and the adoption of new methodologies to enhance resilience. The research also points to the importance of understanding local ecological conditions and incorporating them into broader resilience strategies.

3.4 Port and Infrastructure Resilience

This study enhances our understanding of resilience in port operations and infrastructure networks. Touzinsky et al. (2018) investigated the influence of Hurricane Matthew on three ports in the southeastern US. They utilised vessel-position data to quantify port performance metrics and employed Bayesian changepoint analysis to identify variations in system behaviour. Their study provided valuable insights into quantifying port resilience using empirical data and analytical techniques, enhancing our understanding of how ports respond to and recover from major storms. Praetorius et al. (2015) examined the everyday operations of the vessel traffic service (VTS) system in ports and its contribution to safe and efficient traffic movements. The research highlighted the complexity of the VTS domain and emphasised the need to analyse everyday operations for effective decision making. This study sheds light on the functioning and adaptability of the VTS system, offering important considerations for enhancing the overall performance and resilience of traffic management in ports. Henry and Emmanuel Ramirez-Marquez (2012) proposed generic metrics and formulae for quantifying system resilience over time. The study indicated the importance of considering disruptive events, component restoration and overall resilience strategy in resilience analysis. It provided a valuable framework for quantifying and analysing system resilience, offering insights that can inform effective resilience design strategies across various domains and industries. Baroud et al. (2014) focused on quantifying network resilience, particularly in the context of waterway commodity flows. The study defined network resilience dimensions and introduced stochastic measures for assessing resilience. It also discussed optimisation techniques for resilience strategies. This study contributed to the understanding and quantifying of network resilience, providing useful insights for planning and optimising the resilience of infrastructure networks, especially in the context of waterway commodity flows.

3.5 Port Resilience and Systemic Risk

The study highlights the importance of understanding and managing systemic risks in the context of port resilience. Verschuur et al. (2022) introduced a systemic risk framework for port and supply chain networks. They emphasised the interconnected nature of ports within various networks and the importance of considering systemic risks in risk analyses. The study addressed the potential propagation of disruptions and supply chain losses by highlighting the need to enhance system-wide resilience, including port adaptation and system-level measures. As climate change increases the

frequency of natural hazards, this framework provides a practical approach to mitigate future risks. Hossain et al. (2019) focused on quantifying and assessing the resilience of a deep-water port. By using a Bayesian network and advanced techniques, they identified key factors that enhance the port's resilience during disruptive conditions. This approach provided a systematic way to understand and measure resilience, enabling stakeholders to prioritise maintenance, alternate routing and workforce restoration for improving overall system resilience. Notteboom et al. (2021) compared the effects of the COVID-19 pandemic and the 2008–2009 financial crisis on container shipping and ports. Their study highlighted the importance of adaptation mechanisms in shaping the outcomes during crises. The differences observed in the strategic behaviour of market players and the application of adaptation mechanisms highlight the need for flexibility and dynamic response strategies to address varying crises. Verschuur et al. (2020) shed light on port disruptions caused by natural disasters and the resilience of port and logistics operations. The analysis of vessel tracking data revealed insights into the duration and extent of disruptions, challenging some assumptions commonly made in modelling studies. Furthermore, the findings suggested that substitution between ports is rare during short-term disruptions, but production recapture plays a significant role in maintaining operations. These empirical insights provide valuable information for improving future modelling studies and understanding the practical implications of port resilience.

4. Conclusions

The comprehensive research on maritime transport resilience has significantly affected how this important topic is understood and developed. The review study has offered priceless insights that have informed future investigations and activities by methodically examining current information, spotting trends and revealing gaps. Its effects can be seen in various fields. Primarily, the review study's thorough overview of the difficulties and detrimental effects of maritime transport has been helpful to policymakers and industry players in helping them make decisions and create focused strategies to deal with these problems. By designing a resilient maritime supply chain, industrial practitioners and managers can attain higher precision in navigating disruptions and complex maritime supply chain scenarios. Early adoption of maritime supply chain resilience will improve timely interventions to minimise risks (Al Naimi et al., 2022). The review study has also stimulated more investigation, resulting in a deeper comprehension of the socioeconomic effects of interruptions in maritime transport and the incorporation of cutting-edge technology to improve resilience. The review study's effect may also be seen in the encouragement of inter-disciplinary partnerships because academics from other disciplines understand that they must cooperate to address the complexity of marine transport resilience. Overall, the review study's influence goes beyond academics, influencing laws, customs and inventions that support a robust and sustainable future for maritime transportation. The review study is valuable for senior researchers, young scholars and industrial practitioners for more research in maritime transport resilience systems, along with similar systems such as rail and public transport.

However, this study only examines the existing research trends of maritime transport resilience on the basis of bibliometric analysis. Particular actions on how to attain maritime transport resilience have not been further investigated. As such, particular methods to improve maritime transport resilience can be examined through robust empirical analysis or scenario analysis. This study also concentrates on maritime

transport resilience rather than all types of resilience identified in the paper. It may perhaps be ambitious but worthwhile if forthcoming research would review the resilience literature by different disciplines.

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