Resilience analysis of maritime transportation networks
a systematic review

Zhang, Di; Tao, Jiale; Wan, Chengpeng; Huang, Liang; Yang, Ming

DOI
10.1093/tse/tdae009

Publication date
2024

Document Version
Final published version

Published in
Transportation Safety and Environment

Transportation Safety and Environment, 2024, **6**: tdae009
DOI: 10.1093/tse/tdae009
Review

Resilience analysis of maritime transportation networks: a systematic review

Di Zhang[1,2,4], Jiale Tao[2,3], Chengpeng Wan[1,3,*], Liang Huang[1,3,5,6] and Ming Yang[6,7]

[1]State Key Laboratory of Maritime Technology and Safety, Wuhan University of Technology, Wuhan 430063, China.
[2]School of Transportation and Logistics Engineering, Wuhan University of Technology, Wuhan 430063, China.
[3]Intelligent Transportation Systems Research Center, Wuhan University of Technology, Wuhan 430063, China.
[4]Inland Port and Shipping Industry Research Co., Ltd. of Guangdong Province, Shaoguan 512100, China.
[5]Sanya Science and Education Innovation Park, Wuhan University of Technology, Sanya 572000, China.
[6]Safety and Security Science Section, Faculty of Technology, Policy and Management, Delft University of Technology, Delft 2600GB, Netherlands.
[7]Australia Maritime College, University of Tasmania, Launceston, Tasmania 7005, Australia.
*Corresponding author. E-mail: cpwan@whut.edu.cn

Abstract

As supply chains in today's world become more complex and fragile, enhancing the resilience of maritime transport is increasingly imperative. The COVID-19 epidemic in 2020 exposed the vulnerability of existing supply chains, causing substantial impacts such as supply shortages, procurement constraints, logistics delays and port congestion, highlighting the need to build resilient maritime transportation networks (MTNs) and reigniting research on the resilience of maritime transport. Based on science mapping, we quantitatively analysed the domain of resilience of MTNs. We mainly study the resilience of MTNs from the following aspects: the construction of MTNs and their topological characterization, vulnerability-orientated resilience analysis of MTNs, recovery-orientated resilience analysis of MTNs, investment decision-orientated resilience analysis of MTNs, climate change-orientated resilience analysis of MTNs and pandemic-orientated resilience analysis of MTNs. This study reviews recent advances in MTN resilience research, highlighting research topics, shortcomings and future research agenda.

Keywords: maritime transportation networks (MTNs); science mapping approach; maritime transport resilience

1. Introduction

Maritime transport is the backbone of international trade and the global economy. Bad weather conditions [1], natural disasters [2], terrorist attacks [3], geopolitics [4] and labour strikes [5] are the main factors causing disruptions of maritime transportation networks (MTNs). The dependence of maritime transport on major shipping channels is very evident, especially after the COVID-19 outbreak and the Suez Canal's congestion, making the study of MTN resilience imminent.

As early as 1973, Holling [6] presented the definition of resilience as 'the ability to recover from wild shocks or the unexpected'. Subsequently, researchers gradually applied resilience to other disciplines, including engineering resilience, transportation resilience, ecological resilience, economic resilience and social resilience [7–10]. Another scholar builds on Holling's proposed definition of resilience to derive the concept of recovery further [11]. In an MTN, ports and shipping routes are often disturbed by earthquakes, tsunamis, storms, etc. [12–14]. These disaster events can cause the closure of ports and interruption of MTNs, thus affecting MTN transportation efficiency and causing huge socio-economic losses. Generally speaking, the approach to cope with disasters includes two different methods: one is ex-ante prevention, which aims to reduce the losses caused by disasters. This is achieved through the implementation of defensive measures that minimize the probability of disaster occurrence and enhance the resilience of affected objects; the second is to improve the recovery ability of the involved entities after the event of disasters. MTNs' resistance and recovery capacity significantly impacts maritime transportation's efficient operation. In the study of MTNs, the first approach to responding to disasters reflects the vulnerability of MTNs, which mainly describes the ability of MTNs to resist disasters. The second approach to disaster response demonstrates the resilience of MTNs, which describes primarily their resilience. Considering the two together, 'resilience' must be used. The study of the resilience of MTNs is expected to use external resources reasonably and effectively to recover quickly and reach a normal state even after being affected. Studying the resistance and resilience of MTNs from a resilience perspective can help to improve the flexibility and resilience of MTN structures and functions and assist relevant authorities in taking selective measures to reduce the impact on MTNs. In view of this, this study reviews MTN resilience research in terms of publications, journals, keywords, co-authors, citations and countries, quantitatively summarizes developments in the resilience of MTNs and proposes possible future research agendas.

Most of the existing research has focused on specific topics related to maritime resilience and supply chain resilience, and research on the resilience of MTNs needs to be more extensive by comparison. At the same time, there are insufficient systematic reviews of MTN resilience and fewer quantitative analyses. Given this, some work was conducted in this research, including: 1) analysing the key research topics in the resilience of MTNs

Received: September 16, 2023. **Revised:** December 11, 2023. **Accepted:** March 4, 2024

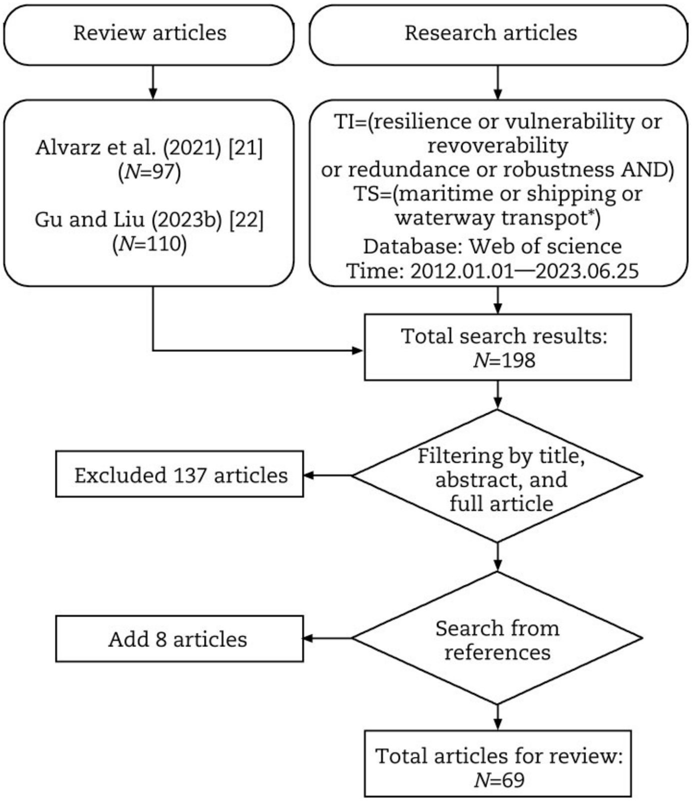

Fig. 1. Research flow chart.

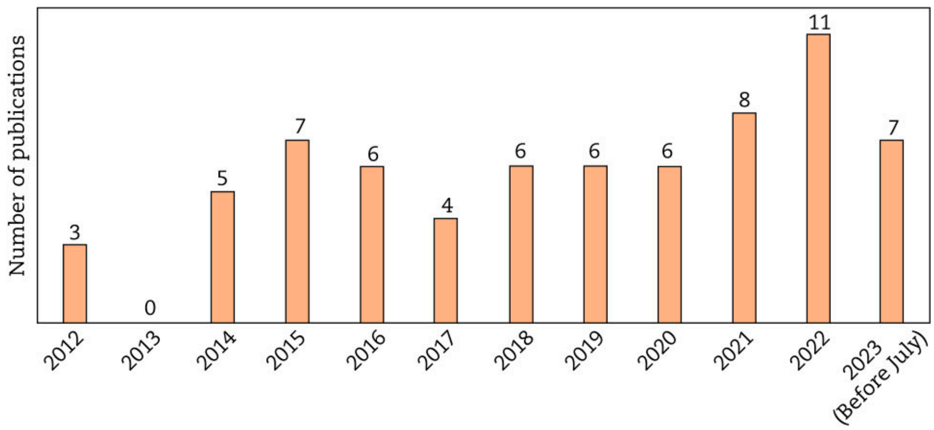

Fig. 2. Yearly publications from 2012 to 2023.

from different perspectives, 2) pointing out the limitations of the current research and 3) raising possible hotspots for future research. The main contributions of this study lie in the following aspects. First, based on a science mapping approach, it examines how journals, scientists, publications and countries are interrelated in the field of resilience of MTN. Second, it summarizes the research hotspots of the resilience of MTNs. Finally, possible future research hotspots are proposed to provide insights for researchers.

The rest of this study is constructed as below. Section 2 describes the process of bibliometric search and science mapping. Section 3 focuses on the presentation of the results of science mapping. Section 4 presents the key topics in the resilience of MTN analysis and possible future research agendas.

2. Methodology

The latest research results in the resilience of MTNs published in *Web of Science* (i.e. 2012–2023) were evaluated using a science mapping method. A systematic review aims to use a method to minimize human bias and provide more reliable findings [15].

2.1. Bibliometric search

Current research [16–18] indicated that vulnerability, recovery, redundancy and robustness are essential components associated with the concept of resilience. Vulnerability reduction and redundancy improvement have been recognized as goals of resilience optimization [19, 20]. Therefore, the literature search is employed

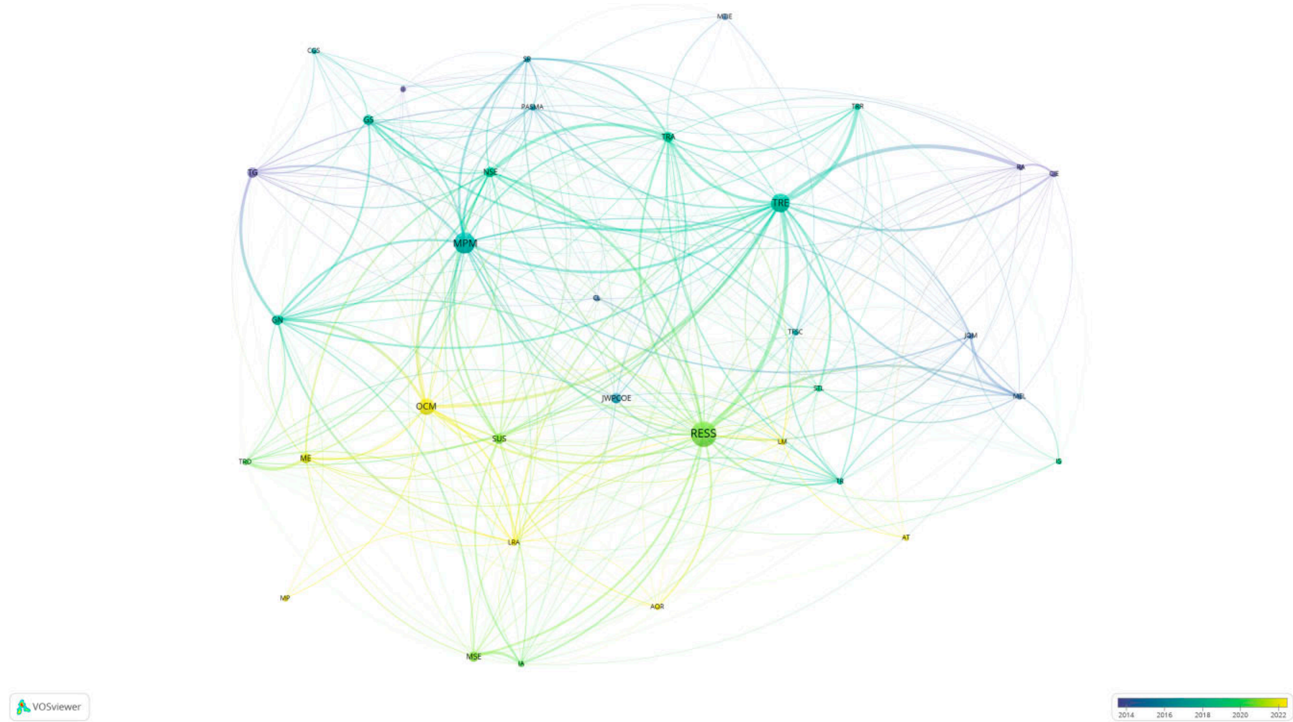

Fig. 3. Journal visualization in the resilience of MTNs.

Table 1. Quantitative analysis of journals on the resilience of MTNs.

Journal	Acronym	Number of Publications	Total citations	Average Citations	Ave. Norm. Citation
Reliability Engineering & System Safety	RESS	7	415	59.3	1.929
Transportation Research Part E-Logistics and Transportation Review	TRE	4	198	49.5	2.179
Maritime Policy & Management	MPM	3	63	21.0	1.076
Transportation Research Record	TRR	3	23	7.7	0.368
International Journal of Maritime Engineering	ME	2	4	2.0	0.091
Journal of Infrastructure Systems	IS	2	14	7.0	0.195
Journal of Marine Science and Engineering	MSE	2	2	1.0	0.066
Journal of Transport Geography	TG	2	12	6.0	0.170
Maritime Economics & Logistics	MEL	2	27	13.5	1.875
Networks & Spatial Economics	NSE	2	27	13.5	0.719
Ocean & Coastal Management	OCM	2	5	2.5	0.362
Sustainability	SUS	2	19	9.5	0.629

by Boolean keywords, where the title, abstract and keywords are limited as follows:

TOPIC TI = (resilience OR vulnerability OR recover∗ OR redundancy OR robustness)

AND

TS = (maritime transport∗ OR maritime shipping OR waterway transport∗ OR maritime network)

In addition, the literature search focused on the last 10 years. To further increase the relevance of the literature, we eliminated literature that contained topics of vulnerability and resilience but did not match the content. During the search, review literature with more similar research topics was found. Álvarez et al. [21] analysed articles related to MTN topology and vulnerability of MTN, incorporating a total of 97 papers in the research framework. Gu and Liu [22] focused on the review of articles related to maritime transport resilience, and a total of 110 papers from the last decade were included in the research framework. This study focuses on MTNs' ability to recover and adapt to challenges, contrasting with the first article's emphasis on complex network analysis for understanding maritime traffic and the second's conceptual framework on resilience in maritime transport. Its novelty lies in offering a multidimensional perspective to understand and enhance the maritime system's capacity to respond to various disruptions, such as natural disasters, economic fluctuations or political changes, highlighting the importance of adaptability, recovery and preparedness.

2.2. Science mapping

Science mapping is a graph that demonstrates the evolution of a discipline or field based on the theoretical methods of bibliometrics, informatics, webometrics, knowledge metrology and scientometrics, which can minimize the artificiality and bias of review studies. It has the dual nature and characteristics of 'graph'

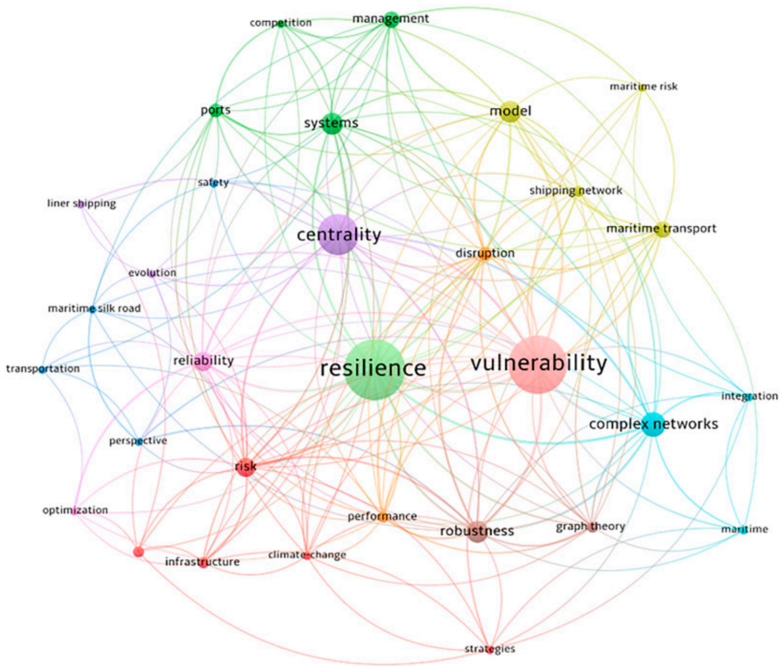

Fig. 4. Visualisation of keywords in the resilience of MTNs.

Table 2. Keywords analysis of the resilience of MTNs.

Keyword	Occurrence	Average citations	Ave. Norm. citation
Resilience	22	59.7	1.2171
Vulnerability	21	52.8	1.1085
Centrality	15	48.5	0.9309
Complex networks	9	56.6	1.2265
Robustness	8	97.0	0.9595
Model	8	13.6	0.7467
Systems	8	16.8	0.8474
Risk	7	63.1	0.8013
Reliability	7	91.3	1.3476
Maritime transport	6	17.0	0.8241
Disruption	5	87.0	1.0700
Ports	5	32.0	1.1387
Performance	4	120.0	1.1812
Graph theory	4	179.0	1.4783
Shipping network	4	3.8	0.4759
Infrastructure	4	43.8	1.3379
Climate change	3	146.0	1.6571
Maritime Silk Road	3	7.7	0.3592
Strategies	3	129.7	1.3526
Competition	3	28.7	1.1368
Evolution	3	26.0	0.7591
Integration	3	56.7	1.7721
Maritime risk	3	47.3	1.5986
Optimization	3	70.3	1.5409
Perspective	3	2.3	0.1184
Safety	3	22.3	0.3904
Liner shipping	3	104.0	1.0639

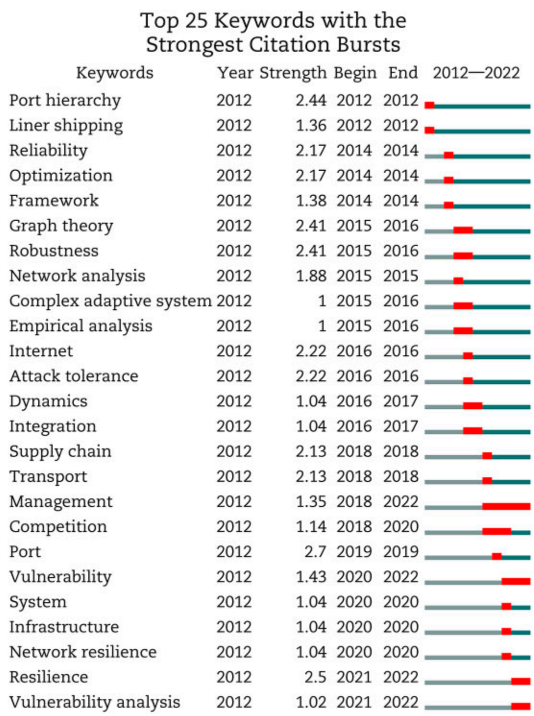

Fig. 5. Evolution of keywords for resilience in MTNs.

and 'spectrum'. As a practical and comprehensive visual analysis method and tool, it has been widely applied and has obtained reliable conclusions, which has attracted more and more scholars' attention. *VOSViewer* is used for network visualization of journals, researchers, institutions, countries, keywords, etc. [23].

3. Results of science mapping

Based on the above search formula, articles from the last 10 years were searched, resulting in 198 relevant articles. The researchers weeded out articles that did not meet the topic requirements, and ultimately selected 69 articles, as shown in Fig. 1.

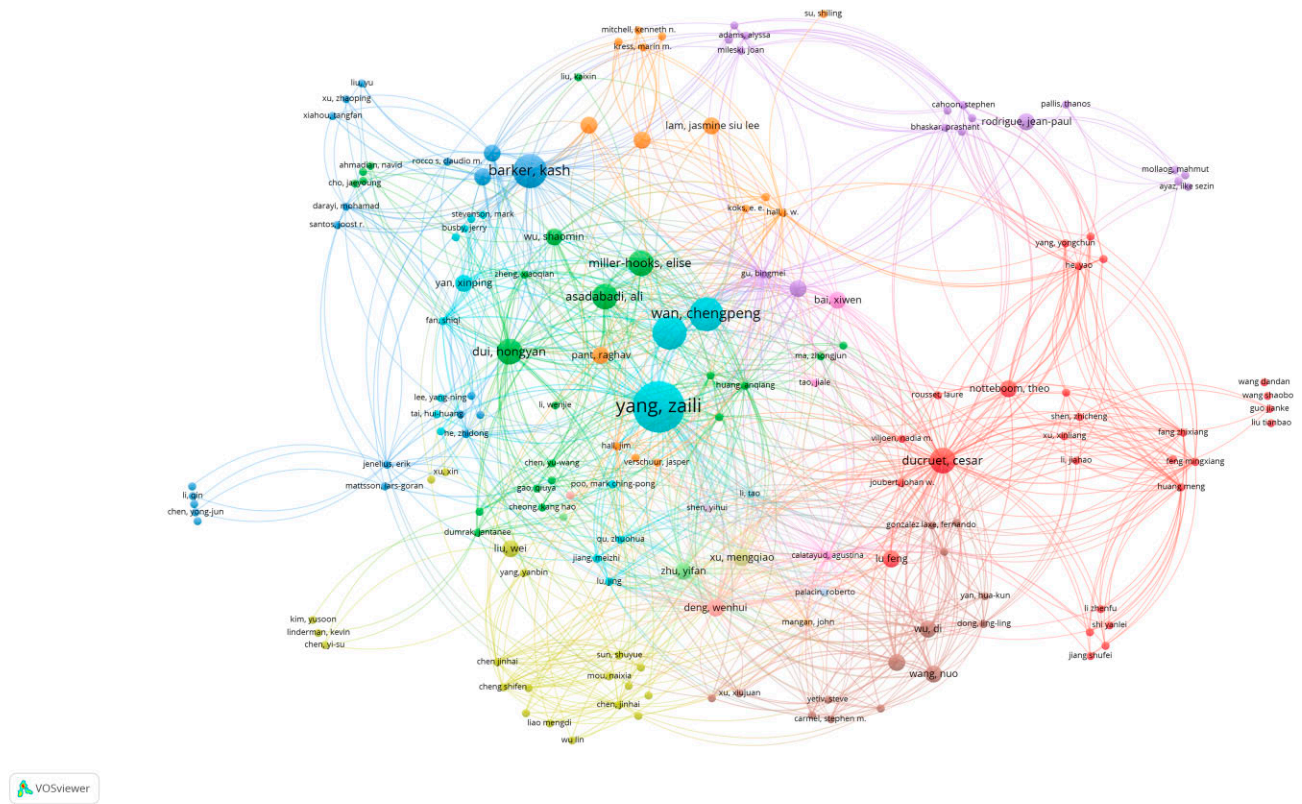

Fig. 6. Citation-authors analysis in the resilience of MTN research.

Table 3. Highly cited literature profile in the resilience of MTNs.

Article	Number of citations	Norm. citations
Mattsson and Jenelius [20]	379	2.425
Tukamuhabwa et al. [27]	328	2.099
Kim et al. [28]	290	1.856
Ducruet and Notteboom [29]	195	2.127
Wan et al. [30]	122	2.773

3.1. Literature review of previous years

Based on screened literature, the number of publications per year was analysed, as shown in Fig. 1. As can be seen from Fig. 2, there has been an increasing focus on the resilience of MTNs in recent years, with a large part of the reason being the impact of COVID-19 (which started to increase in 2021). Overall, the number of articles in this paper is still relatively small compared to well-established fields such as maritime safety (572 papers), studied by Luo and Shin [24], and maritime transport risk (1181 papers), studied by Huang et al. [25].

3.2. Journal sources analysis

Based on science mapping, this study analyses the journals to which the retrieved articles belong. Fig. 3 provides a comparative analysis of the journals and the number of articles published, as well as their interrelationship.

In Fig. 3, the colour of the line segments between nodes is an indication of the interconnectedness of journals. Nevertheless, it only partially represents the quality of the article. As shown in Fig. 3, *Reliability Engineering & System Safety* (RESS), *Transportation Research Part E-Logistics and Transportation Review* (TRE), *Maritime Policy & Management* (MPM), *Transportation Research Record* (TRR) *and International Journal of Maritime Engineering* (ME) have made significant contributions to the research of MTN resilience.

Four indicators are presented in Table 1, including the number of publications, total citations, average citations and average normalized number of sources. To some extent, they quantitatively evaluate the impact of the journals. RESS and TRE are the two journals with the highest number of publications and the highest average number of citations, respectively, as shown in Table 1, indicating their high level of recognition in the field. Table 1 also lists a number of journals that are less dominant in terms of their performance on the indicators but which deserve attention, such as *Networks & Spatial Economics* (NSE), *International Journal of Maritime Engineering* (ME), *Journal of Infrastructure Systems* (IS) and *Journal of Marine Science and Engineering* (MSE). Regarding the publications and citations, TRE and MEL (Maritime Economics & Logistics) are less influential than RESS, still, regarding Ave. Norm. These three journals are less influential in the resilience of MTN, where the number of publications and the time of publication are the key factors. For an ideal evaluation of the impact of a journal or paper, more citations are needed, and a combined judgement based on the methods in the latter section is required.

3.3. Co-occurrence of keywords

Keywords are the central summary of a study. Identifying relationships between topics through the frequency of occurrence between keywords in the research area is a direct reflection of current research hotspots. As shown in Fig. 4 and Table 2, we filtered some of the unsuitable ones, such as complex network, complex networks, network and shipping networks, and finally retained 31 major keywords. Similarly, the visualization metric

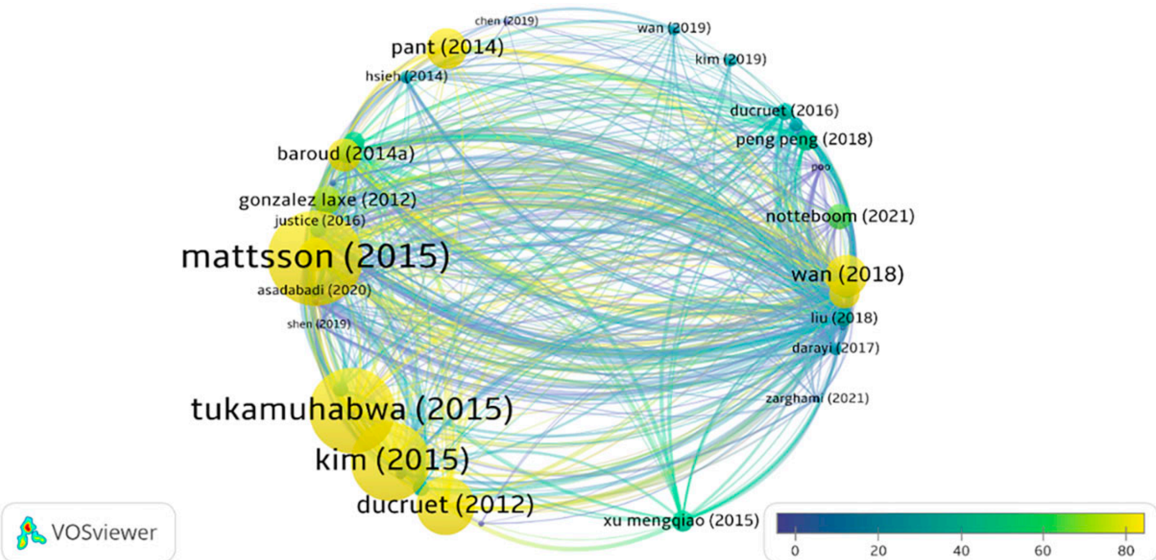

Fig. 7. Visualisation of highly cited literature in the resilience of MTN research.

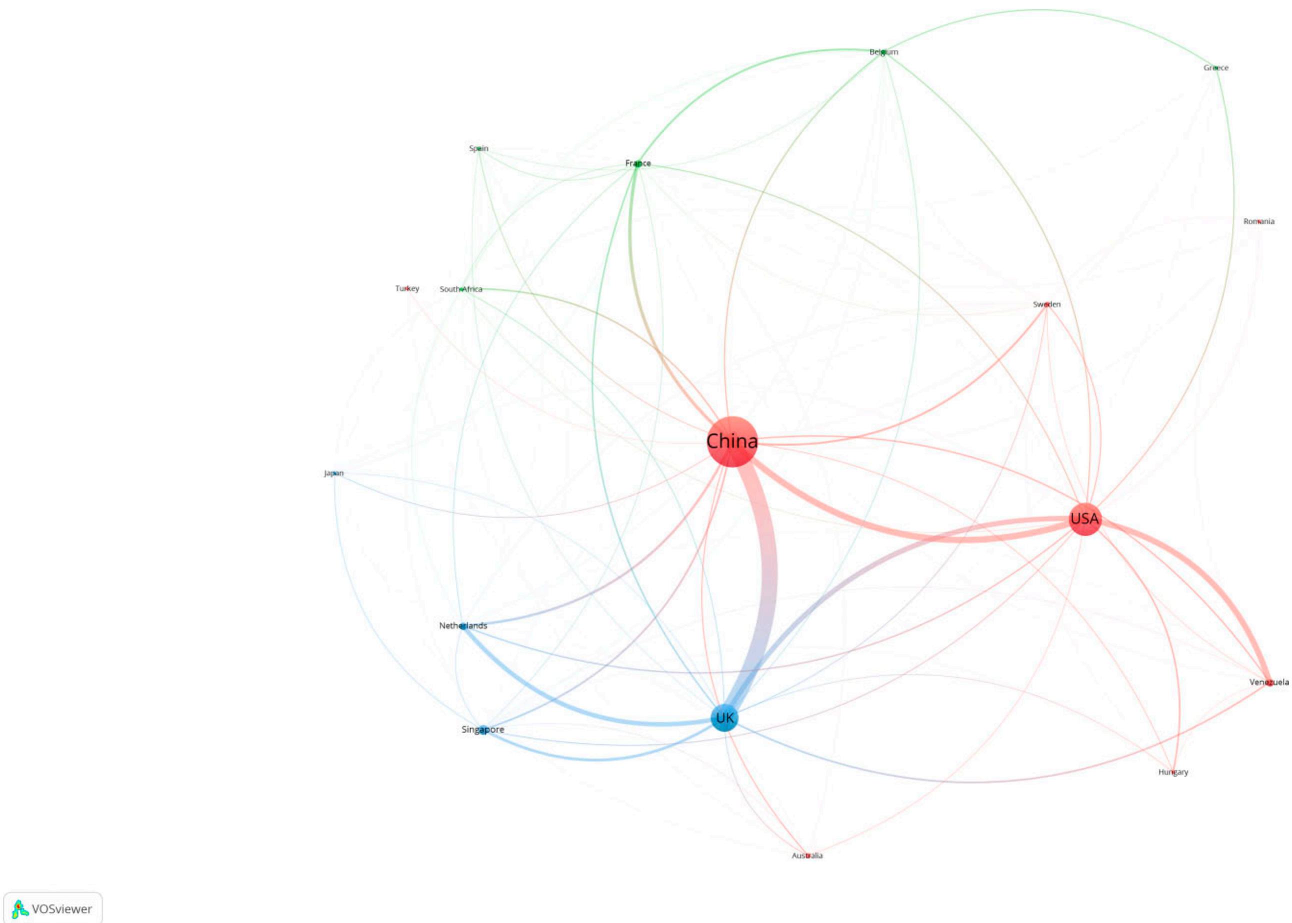

Fig. 8. Mapping of countries' cooperation in the resilience of MTN research.

of the keywords in Fig. 4 is chosen as the frequency of their occurrence.

Table 2 shows the evaluation of quantitative indicators for keywords. The visualization of the frequency of occurrence is shown in Fig. 4. Resilience, vulnerability and centrality occupy a central position, which is the hotspot of study. From the average citations, it can be found that graph theory is the basis of MTN research as much as other keywords. Climate change is another topical issue of interest to researchers, which has a significant impact on the safety of transport infrastructure, and mitigating the effects of

Table 4. Countries active in MTN research.

Country	Number of publications	Number of citations	Average citations	Ave. Norm. citation
China	28	626	22.4	0.8676
USA	17	1016	59.8	1.1595
UK	14	990	70.7	1.5240
Singapore	4	166	41.5	1.3686
France	3	269	89.7	1.2590
Netherlands	3	89	29.7	1.5420
Venezuela	3	314	104.7	1.5258
Australia	2	34	17.0	0.4386
Belgium	2	318	159.0	2.4635
Sweden	2	419	209.5	1.1529

climate change by reducing carbon emissions from shipping has always been of interest to researchers [26]. Integration, climate change and maritime risk-related themes, while not of greater importance across all indicators, remain hot issues of continuing interest to researchers. The emergence of a new field may indicate the development direction of the theme.

The results obtained by the most powerful citation bursts identify the trend of the theme of maritime shipping resilience over time, as shown in Fig. 5. Bursts refer to keywords with a sudden increase in word frequency in different periods, and the higher the frequency of keywords in the literature, the greater the attention of the keyword in the relevant academic research field. 'Begin' and 'End' represent the start and end years that the keywords highlight. The period highlighted by the keywords marked in red is arranged in the order of the year in which the keyword is highlighted, and the result can be determined in which years the hot keywords appear and when they end. It can be seen from the strength value that the resilience of MTNs has changed several relatively prominent research hotspots in the past 10 years. In 2012, the main focus was on liner shipping and port hierarchy; in 2015, the research on graph theory and robustness in this field attracted attention; in 2016, cyberattacks became a new research hotspot, until the past two years, when the significant impact of the epidemic in the shipping industry has led researchers to focus on the resilience of MTNs. The latest study focuses more on the vulnerability and resilience of port infrastructure and MTNs.

3.4. Citation analysis

1) Citation-authors analysis

Citation-authors analysis examines the interactions between scholars in a field of study, mapping different periods so scholars can review the trajectory of knowledge development in collaborative networks while providing valuable information for future scholars to help collaborate with established scholars in the field of study. In this study, the resilience of the MTN domain is analysed by the citation-authors, as shown in Fig. 6. Some groups are not connected, and only the most prominent groups are shown in Fig. 6. As the central point in the largest cluster, Zaili Yang is one of the prominent authors in the field.

As the most published scholar, Yang's research interests are analysing and modelling transport networks' safety, resilience and sustainability, particularly maritime and logistics systems. In addition, two other scholars have published articles in this field more frequently. Cesar Ducruet concentrated on the spatial structure of transport networks, health issues in port cities, port-city socio-economic relationships, and vulnerability in transport systems. His research provides a detailed account of the long-term evolution of shipping networks from a global perspective, carrying out a wealth of research on topics such as key channels, port cities, maritime transport flows and network disruptions.

2) Citation-document analysis

Unlike the citation-authors analysis above, literature citations quantitatively evaluate an article's standing in its field of study. The number of citations to a representative article is a direct reflection of the author's status. Table 3 provides a quantitative evaluation of the six most cited papers. Fig. 7 is a visualization of the most recognized literature on shipping network resilience in recent years. The authors represented by the yellow nodes are the most recognized in the field of MTN resilience in Table 3. Clearly, the most prominent literature is Mattsson and Jenelius [20]. This article is a synthesis of the research on vulnerability and resilience of transport systems at that time. After analysing the more prominent literature, it was found that more than half of these articles were review articles, which usually tend to achieve a more significant number of citations. The most recent one was published five years ago, and there needs to be more reviews on the resilience of MTNs. As a review article, this paper explores current research and brings forward possible future research hotspots.

3.5. Country cooperation mapping

Fig. 8 is a visualization of the inter-country cooperation relationship, which is quantitatively analysed in Table 4. Intuitively, the prominence of a node represents the current state of the country's development in the resilience of MTN. In terms of the number of articles, China, the United States and the United Kingdom are far ahead of other countries. But in terms of the total number of citations and average citations, Belgium and Sweden occupy a considerable advantage.

4. Research topics and agenda

Based on the science mapping analyses described above, this study provides an overview of the current keywords co-occurrence, paper publication, citation analysis and countries active in the resilience of MTN research. Next, this study will analyse current research limitations and provide unique insights into future research trends by refining the key topics in the resilience of MTN research.

4.1. Key topics in the resilience of MTN analysis

4.1.1. *The data source of MTN modelling*

As the basis of the resilience of MTN research, constructing a complete and accurate MTN is the first challenge we have to face. The data sources in the literature in recent years are summarized in Table 5, and we found that consulting agencies, shipping service information and relevant reports are the more common ways to obtain data. In addition, weight is also one of the critical indicators reflecting the characteristics of MTN. Thanks to the development of computer technology, establishing a shipping database makes MTN more complete and the academic community is increasingly interested in the research of weighted network. However, how to obtain container capacity in each direction between regions has troubled many scholars. It is crucial to reflect global shipping activities accurately. Meanwhile, due to the scarcity of data for long-term studies, the data used in major shipping studies can only meet the needs for short-term studies, and fewer studies have constructed long-term network matrix datasets [31, 32]. Remark-

Table 5. Data source used for MTN construction.

Author	Database	Data	Weighted or unweighted	Directed or undirected
Gonzalez Laxe et al. [33]	Lloyd	Container ship call data	Weighted	Directed
Xu et al. [34]	Containerization International	Container ship route information	Weighted	Directed
Ducruet [35]	Lloyd	Container ship trajectory data	Weighted	Undirected
Wang et al. [36]	Some world-leading shipping companies	Container ship route information	Unweighted	Undirected
Calatayud et al. [37]	Containerization International	Container ship route information	Weighted	Directed
Liu et al. [38]	Maersk shipping line	Container ship route information	Weighted	Directed
Fang et al. [39]	A global AIS dataset http://www.myships.com/myships/	AIS data	Weighted	Undirected
Wu et al. [40]	Unknown	Container ship route information	Weighted	Undirected
Shen et al. [12]	World Meteorological Organization China Ports website	Container ship route information	Unweighted	Undirected
Rousset and Ducruet [41]	Lloyd's List Intelligence	Actual vessel movement data	Weighted	Undirected
Mou et al. [42]	Tanker AIS trajectory data	AIS	Weighted	Directed
Wan et al. [43]	Alphaliner some world-leading shipping companies' official website.	Container ship route information	Unweighted	Directed
Wan et al. [44]	Alphaliner officially published information	Container ship route information	Weighted	Directed
He et al. [45]	China Ports China Shipping Gazette	Container ship route information	Unweighted	Undirected
Xu et al. [46]	Alphaliner	Container ship route information	Weighted	Undirected

ably, some scholars use automatic identification system (AIS) data for MTN modelling, making obtaining data to support subsequent studies easier.

4.1.2. *Modelling and topological analysis of MTNs*

Network models usually comprise nodes and edges. In the context of MTN research, these nodes often stand for ports, and at times for entire regions or countries. The edges that connect these nodes signify trade interactions, which are usually represented as actual shipping routes. The Graph of Direct Links (GDL) and the Graph of All Links (GAL) are the two prominent approaches to constructing network models [29]. Under the GDL approach, ports are exclusively connected to their neighbouring ports in accordance with the sequence of stops in shipping routes. The criteria consider solely ports that hold direct trade links with each other. Conversely, the GAL approach posits that there are connections between ports irrespective of whether there is a direct trade link. Consequently, any port can achieve contact with any other port via intermediary ports.

MTN topology characteristics are the basis for empirical research and the prerequisite for research work on the resilience of MTNs, where researchers have achieved a wealth of research results. As the fundamental indexes to describe the topology of MTN, degree, shortest path length, clustering coefficient, network efficiency and centrality [34, 37, 38, 40, 43, 47] are widely used on the resilience of MTN research, as shown in Table 6. However, with the gradual improvement of MTN research, independent metrics are not suitable for comprehensive evaluation of MTNs, and the use of multiple indicators to analyse MTN characteristics from different perspectives gradually emerges [37, 40]. Calatayud et al. [37] adopted a multiplexed network approach, using network analysis metrics to analyse topological characteristics from different perspectives. Degree, network diameter, clustering coefficient, beta and gamma indices are used to evaluate the network performance. Betweenness centrality was used to estimate the importance of nodes in MTNs. Based on these studies, it is novel for researchers to derive new evaluation indicators [43, 48] or to customize new indicators [18, 49, 50].

Given the complexity of MTNs, the perspectives on the resilience of MTN research are equally diverse, for example, review [21, 22], computer simulation [51], modelling analysis [52] and case study [41]. This study will provide an introduction to the mainstream research fields on the resilience of MTNs in terms of the following topics.

4.1.3. *Vulnerability-orientated resilience analysis of MTNs*

The resilience of MTN is crucial for ports and liner services. Should external risk factors, such as port accidents, force a halt in operations, the impact is directly felt by the connected liner services, thereby diminishing their utility. Similarly, disturbances in key areas or specific maritime transport corridors can disrupt shipping routes traversing these corridors or regions. This disruption not only reduces transport efficiency but may also lead to widespread systemic disruptions. Thus, protecting the network by identifying the risk factors affecting the MTN is crucial. This section conducts vulnerability analysis mainly from the perspective of network nodes (ports, countries or regions, and key maritime channels).

Table 6. Topology characteristics and centrality-related parameters of MTNs.

Reference	Degree	Shortest path length	Clustering coefficient	Network efficiency	Isolated nodes	Centrality			
						Degree centrality	Betweenness centrality	Closeness centrality	Eigenvector centrality
Gonzalez Laxe et al. [33]	✓								
Xu et al. [34]		✓							
Wang et al. [36]	✓	✓	✓		✓				
Viljoen and Joubert [53]	✓	✓	✓		✓		✓		
Calatayud et al. [37]	✓	✓	✓				✓		
Liu et al. [38]	✓		✓	✓		✓	✓	✓	
Wu et al. [40]	✓	✓	✓		✓				
Shen et al. [12]	✓	✓	✓						
Rousset and Ducruet [41]			✓				✓		
Mou et al. [42]	✓					✓			
Zarghami and Dumrak [48]							✓	✓	✓
Wan et al. [43]						✓	✓	✓	
Yang and Liu [47]				✓					
Poo and Yang [26]			✓	✓		✓	✓	✓	
Xu et al. [46]	✓			✓			✓		
He et al. [45]	✓		✓	✓			✓		

1) Port vulnerability

It has been shown that network efficiency and connectivity indicators are very suitable for evaluating the resilience of MTNs [45, 47, 54, 55], but there is not a consensus evaluation method yet [53, 56]. Peng et al. [56] assessed the resilience of a typical cargo ship transportation network from four perspectives, specifically random attack, degree-based attack, betweenness-based attack and flux-based attack. With respect to network vulnerability, Viljoen and Joubert [53] compared different disruption strategies: link betweenness and link salience. They found that both strategies reduce network flexibility, but betweenness does so to a greater extent, resulting in reduced flow of goods between major shipping lanes.

It then discusses the degree of overall resilience of different network structures, the factors influencing them and the various optimization strategies. By removing key nodes, Guo et al. [57] analysed the vulnerability of the China-Japan-Korea MTN. In China, the impact of major hub ports on the stability of the shipping network is more pronounced than in the ports of Japan and Korea. This is most notable in the more developed coastal regions, such as Shanghai, Ningbo and Lianyungang. Yang and Liu [47] assessed the resilience of MTNs by utilizing the method of deleting nodes and identifying the critical ports in MTNs. The results show that the addition of hub ports and the backup of critical nodes are effective in strengthening the resilience of MTNs.

2) Regional and national vulnerability

As a major support for global trade, maritime transport is a complex network encompassing ports around the world. Although studying the overall MTN is desired by researchers, one difficulty is of obtaining long-term data, and another is that shipping networks include multiple countries and regions; their interactions are what we want to explore. There are relatively few studies on global MTNs, and the data needs to be updated. Ducruet [58] built a global maritime network based on Lloyd's List for selected months in 2008. The results show that MTNs rely more on those hub nodes which have higher degree values and flows. Based on container route data, Xu et al. [46] investigated the variation of port congestion in MTNs while quantitatively assessing the impact of cascading failures on the resilience of MTNs. He et al. [45] presented a resilience evaluation framework under disasters by analysing the dynamic evolution of MTN resilience.

More studies focus on countries (China-USA, China-Japan, etc.), regions (Eurasia, Americas, the Belt and Road) and shipping companies. Hu et al. [59] examined Japan's trade flows in the global MTN and analysed the connectivity of Japan's ports to the world. Calatayud et al. [37] constructed an inter-American shipping network that included 32 countries, as well as a deliberate attack simulation on some of the hub nodes. Mou et al. [60] analysed the distribution of maritime flows along the 21st Century Maritime Silk Road, comparing changes in flows between regions and analysing their interrelationships. Fremont [61] took into account the evolution of the MTN container shipping company Maersk.

3) Vulnerability of key maritime channels

The Strait of Malacca, the Suez Canal and the Panama Canal are the principal passages in MTNs. They are essential routes for maritime transport between the Indian Ocean and Pacific Ocean, the Mediterranean Sea, the Indian Ocean and the Atlantic Ocean. Most of the ships travelling on these significant shipping lanes are long-haul vessels, and their proper functioning is critical to the stability of the global economy. Based on data from container liner companies, Wu et al. [40] quantitatively assessed the impact of key maritime channel disruptions on MTNs. The results show that key maritime channels are one of the key drivers of MTN vulnerability and are critical to the normal operation of MTNs. Based on graph-theoretical methods, Ducruet [35] analysed the impact of removing canal-dependent flows from the MTNs. Although dependence on channels is declining to some extent, some regions are relatively more dependent, such as Asia, Europe and North America. Zeng et al. [62] investigated the potential role of the Carat Canal in MTNs. Results show that the Carat Canal leads to changes in flows in the Strait of Malacca, resulting in the reorganization of trade flows between hub ports and contributing to the evolution of the MTNs.

4.1.4. *Recovery-orientated resilience analysis of MTNs*

Many researchers have adopted a similar definition to Holling [6] – the ability of a system to resist and absorb external influences [10] – but consideration of post-disaster resilience still needs to be improved. Fang et al. [63] analysed the relationship between repair time and resilience changes, and further explored the criticality of network performance. Dui et al. [64] proposed a cost-based approach to system maintenance that further considered the impact of cost and time on system resilience. Dui et al. [65] proposed a measure of node residual resilience that can dynamically adjust the network traffic and select the optimal recovery strategy by evaluating the resilience of nodes. Wan et al. [44] analysed network resilience from a cost perspective and designed network recovery steps based on different metrics.

4.1.5. *Investment decision-orientated resilience analysis of MTNs*

Based on investment decisions and strategic investments, some scholars have made a novel evaluation of MTN vulnerability. Using network game theory, Chen et al. [66] examined the investment decisions of container transportation network participants and analysed the impact of their behaviour on the resilience of the container transportation network at the time of investment. Asadabadi and Miller-Hooks [50] investigated a model based on game theory, which they used to propose a method to assess network resilience. Jiang et al. [67] used a mixture of fuzzy theory and evidential reasoning methods for port vulnerability assessment, ranking the vulnerability of key ports. Li et al. [68] focused on investigating the effect of cooperation and investment strategies on the resilience of MTN.

4.1.6. *Climate change-orientated resilience analysis of MTNs*

Furthermore, some other scholars also analysed the vulnerability of MTNs and their post-disaster recovery from the perspective of natural disasters and terrorist attacks. By removing ports from different classes of tropical cyclones, Shen et al. [12] examined the vulnerability of the Northwest Pacific and North Indian Ocean MTNs to the effects of tropical cyclones. The results show that the performance of the MTNs did not change significantly even after being exposed to the disturbance of a tropical cyclone. Verschuur et al. [2] analysed port disruptions worldwide that have been affected by natural disasters. The results showed that usually several ports were affected and closed at the same time, and it was not possible to prove that port substitution had occurred. Poo and Yang [26] innovatively combined climate metrics, common network analysis metrics and route optimization to investigate the extent to which climate affects network resilience.

4.1.7. *Pandemic-orientated resilience analysis of MTNs*

Last but not least, the COVID-19 pandemic of recent years has caused unprecedented disruption to the global supply chain, port and shipping industry. A series of uncertain events such as soaring freight rates [69], blank sailing schedules [70], port congestion [71], labour shortages [72] and the return of empty containers [73] has exposed the lack of resilience of MTNs. Cullinane and Haralambides [74] examined the various impacts of the epidemic on shipping, including shipping line alliances, port operations and policies. Notteboom et al. [75] compared and contrasted the financial crisis with the extent to which the shipping industry has been affected by COVID-19. Results show that each shock may bring new opportunities.

4.2. Future research agenda

In this section, we delve into the complex interplay and distinctive characteristics of the six aspects of MTN resilience. Beginning with topological analysis, we lay the groundwork for understanding the structural backbone of MTNs. This analysis is crucial as it sets the context for comprehending the nuances of vulnerability- and recovery-orientated approaches. While vulnerability-orientated resilience highlights the potential weak points and risks within the network, the recovery-orientated perspective focuses on strategies and capabilities to rebound from disruptions. The investment decision-orientated analysis then bridges these concepts by exploring how strategic financial inputs can bolster the network's resilience against identified vulnerabilities and aid in quicker recovery post disruption. Furthermore, the climate change-orientated analysis adds another layer, examining how environmental factors uniquely challenge the resilience of MTNs, necessitating specialized adaptive strategies. Lastly, the pandemic-orientated resilience analysis, accentuated by recent global events, sheds light on MTNs' response to unprecedented large-scale disruptions, underscoring the need for agile and comprehensive resilience planning. This holistic view, encapsulating all six aspects, underscores the multifaceted nature of MTN resilience, illustrating how each aspect, while distinct in its focus, collectively contributes to a more resilient and robust maritime transportation network. Building upon this comprehensive analysis, we identify potential avenues for future research agendas, as follows:

1) The resilience of MTN in the post-epidemic era

Maritime transport is fundamental to the global economy's integrated development and the robust functioning of global supply chains. Ports and shipping carry more than 90% of the world's cargo. Over the past three years, the port and shipping industry has experienced unprecedentedly significant market volatility and a volatile environment, with increased congestion, soaring freight rates, loading delays and disruptions to maritime supply chains. COVID-19 and its associated restrictions have also caused severe disruptions to ports, and port-level risks will, in turn, continue to be passed on and amplified across global supply chains and cross-border trade. In addition to the COVID-19 pandemic, escalating geopolitical conflicts, increasing trends of counter-globalization and new technological changes have put enormous pressure on port and shipping management. Therefore, in a volatile and uncertain environment, it is essential to strengthen risk management [76] in ports and shipping and enhance their resilience management capabilities in order to ensure the resilience of global supply chains.

2) Relationship between climate change and carbon emission policies on the resilience of MTNs

Climate change is a challenging global issue, impacting countries politically, economically and culturally. The international shipping industry has significantly contributed to global greenhouse gas emissions, accounting for 3% of global greenhouse gas emissions yearly. The ongoing challenge for shipping companies is how to cope with increasingly stringent policies to reduce emissions from shipping [77, 78]. Climate change is enabling new routes to be opened up-polar routes. Compared to traditional routes, these routes are much shorter, save operational costs, reduce carbon emissions and are known as green routes, helping the shipping industry combat climate change and achieve carbon neutrality targets.

3) Optimization and reconstruction of MTNs

This research direction emphasizes enhancing the resilience of MTNs through meticulous design and planning strategies. It encompasses the optimization of shipping routes and port configurations, the integration of multimodal transportation systems and consideration of environmental constraints, such as climate change. The primary objective is to augment the MTNs' capacity to respond and recover from various external disruptions, like natural disasters and economic instability, while maintaining operational efficiency, thereby increasing MTNs' redundancy and resilience.

4) Emergency management and recovery for MTNs

This research direction focuses on exploring rapid and effective response and recovery strategies for MTNs in the face of sudden events. It includes disaster risk assessment, allocation of emergency resources and design of temporary alternative routes. Moreover, the research will also pay attention to optimizing network structures and operational modes during the recovery phase to enhance MTNs' capacity to withstand and recover from future challenges.

5. Conclusion

This study uses a systematic review approach to evaluate network resilience based on the scientific-mapping method. By analysing 62 pieces of shipping network resilience literature from the last decade, the study presents the key topics in the resilience of MTN analysis and possible future research agenda.

1) The most influential journals in the resilience of MTN research include *Reliability Engineering & System Safety* (RESS), *Transportation Research Part E-Logistics and Transportation Review* (TRE), *Maritime Policy & Management* (MPM) and *Transportation Research Record* (TRR).
2) Co-author analysis examines the interactions between scholars in a field of study, mapping different periods so scholars can review the trajectory of knowledge development in collaborative networks, while providing valuable information for future scholars to help collaborate with established scholars in the field of study. Zaili Yang is the author of the largest number of papers published on the resilience of MTNs and has considerable influence.
3) Resilience, vulnerability and centrality occupy a central position, which is the hotspot of study. From the average citations, it can be found that graph theory is the basis of MTN research as much as other keywords. Climate change is another hot issue of interest to researchers, which is directly related to the safety of transportation infrastructure, and mitigating the impact of climate change by reducing the carbon footprint of maritime transport has always attracted researchers.

The key topics include the construction of MTNs and their topological characterization, vulnerability-orientated resilience analysis of MTNs, recovery-orientated resilience analysis of MTNs, investment decision-orientated resilience analysis of MTNs, climate change-orientated resilience analysis of MTNs and pandemic-orientated resilience analysis of MTNs. Possible hotspots for future research in the field of MTN resilience may include MTN resilience in the post-pandemic era, MTN resilience in the context of the regional conflict and the impact of climate change and carbon emission policies on MTN resilience.

Acknowledgements

This work is supported by the National Key R&D Program of China (Grant No. 2023YFC3107903), the National Natural Science Foundation of China (Grant No. 51920105014 and 51909202), the Young Elite Scientist Sponsorship Program by CAST (Grant No. 2021QNRC001), Hainan Provincial Joint Project of Sanya Yazhou Bay Science and Technology City (Grant No. 2021JJLH0012), and innovation and entrepreneurship team import project of Shaoguan City (Grant No. 201208176230693).

Conflict of interest statement

The authors declared no potential conffiicts of interest with respect to the research, author- ship, and/or publication of this article.

References

1. Garcia-Alonso L, Moura TGZ, Roibas D. The effect of weather conditions on port technical efficiency. *Marine Policy*. 2020;**113**:103816.
2. Verschuur J, Koks EE, Hall JW. Port disruptions due to natural disasters: Insights into port and logistics resilience. *Transportation Research Part D: Transport and Environment*. 2020;**85**:102393.
3. Zelenkov M, Laamarti Y, Charaeva M et al. Maritime terrorism as a threat to confidence in water transport and logistics systems. *Transportation Research Procedia*. 2022;**63**:2259–67.
4. Noorali H, Flint C, Ahmadi SA. Port power: Towards a new geopolitical world order. *Journal of Transport Geography*. 2022;**105**:103483.
5. Gong Z, Liu N. Mitigative and adaptive investments for natural disasters and labor strikes in a seaport-dry port inland logistics network. *Maritime Policy & Management*. 2020;**47**(1):92–108.
6. Holling CS. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*. 1973;**4**(1):1–23.
7. Cox A, Prager F, Rose A. Transportation security and the role of resilience: A foundation for operational metrics. *Transport Policy*. 2011;**18**(2):307–17.
8. Ahern J. Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology*. 2013;**28**(6): 1203–12.

9. Martin R, Sunley P. On the notion of regional economic resilience: conceptualization and explanation. *Journal of Economic Geography*. 2015;**15**(1):1–42.
10. Hollnagel E, Woods DD, Leveson N. *Resilience engineering: Concepts and precepts*: Ashgate Publishing, Ltd.; 2006.
11. Timmerman P. *Vulnerability. Resilience and the collapse of socieiy: A review of models and possible climatic applications. Environmental Monograph No. 1*, Toronto, Canada: Institute for Environmental Studies, University of Toronto, 1981.
12. Shen Z, Xu X, Li J, Wang S. Vulnerability of the Maritime Network to Tropical Cyclones in the Northwest Pacific and the Northern Indian Ocean. *Sustainability*. 2019;**11**(21):6176.
13. Zhang Y, Lam JSL. Estimating the economic losses of port disruption due to extreme wind events. *Ocean & Coastal Management*. 2015;**116**:300–10.
14. Becker A, Ng AKY, McEvoy D et al. Implications of climate change for shipping: Ports and supply chains. *WIREs Climate Change*. 2018;**9**(2):e508.
15. Higgins JP, Thomas J, Chandler J et al. *Cochrane handbook for systematic reviews of interventions*. John Wiley & Sons, 2019.
16. Faturechi R, Miller-Hooks E. A Mathematical Framework for Quantifying and Optimizing Protective Actions for Civil Infrastructure Systems. *Computer-Aided Civil and Infrastructure Engineering*. 2014;**29**(8):572–89.
17. Hosseini S, Barker K, Ramirez-Marquez JE. A review of definitions and measures of system resilience. *Reliability Engineering & System Safety*. 2016;**145**:47–61.
18. Ahmadian N, Lim GJ, Cho J et al. A quantitative approach for assessment and improvement of network resilience. *Reliability Engineering & System Safety*. 2020;**200**(5):106977.
19. Ip WH, Wang D. Resilience and Friability of Transportation Networks: Evaluation, Analysis and Optimization. *IEEE Systems Journal*. 2011;**5**(2):189–98.
20. Mattsson L-G, Jenelius E. Vulnerability and resilience of transport systems - A discussion of recent research. *Transportation Research Part a-Policy and Practice*. 2015;**81**:16–34.
21. Álvarez NG, Adenso-Díaz B, Calzada-Infante L. Maritime Traffic as a Complex Network: a Systematic Review. *Networks and Spatial Economics*. 2021;**21**(2):387–417.
22. Gu B, Liu J. A systematic review of resilience in the maritime transport. *International Journal of Logistics Research and Applications*. 2023; 1–22.
23. van Eck NJ, Waltman L. Visualizing Bibliometric Networks. In: Y Ding, R Rousseau, D Wolfram, (eds.) *Measuring Scholarly Impact: Methods and Practice*. Cham: Springer International Publishing; 2014, 285–320.
24. Luo MF, Shin SH. Half-century research developments in maritime accidents: Future directions. *Accident Analysis and Prevention*. 2019;**123**:448–60.
25. Huang X, Wen Y, Zhang F et al. A review on risk assessment methods for maritime transport. *Ocean Engineering*. 2023;**279**:114577.
26. Poo CP, Yang Z. Optimising the resilience of shipping networks to climate vulnerability. *Maritime Policy & Management*. 2022;**51**(1):15–34.
27. Tukamuhabwa BR, Stevenson M, Busby J et al. Supply chain resilience: definition, review and theoretical foundations for further study. *International Journal of Production Research*. 2015;**53**(18):5592–623.
28. Kim Y, Chen Y-S, Linderman K. Supply network disruption and resilience: A network structural perspective. *Journal of Operations Management*. 2015;**33–34**:43–59.
29. Ducruet C, Notteboom T. The worldwide maritime network of container shipping: spatial structure and regional dynamics. *Global Networks-a Journal of Transnational Affairs*. 2012;**12**(3):395–423.
30. Wan C, Yang Z, Zhang D et al. Resilience in transportation systems: a systematic review and future directions. *Transport Reviews*. 2018;**38**(4):479–98.
31. Robinson R, Chu D. Containerization and the port of Hong Kong in the 1970s. *Australian Geographer*. 1978;**14**(2):98–111.
32. Ducruet C. The geography of maritime networks: A critical review. *Journal of Transport Geography*. 2020;**88**(3):102824.
33. Gonzalez Laxe F, Freire Seoane MJ, Pais Montes C. Maritime degree, centrality and vulnerability: port hierarchies and emerging areas in containerized transport (2008-2010). *Journal of Transport Geography*. 2012;**24**:33–44.
34. Xu M, Li Z, Shi Y et al. Evolution of regional inequality in the global shipping network. *Journal of Transport Geography*. 2015;**44**:1–12.
35. Ducruet C. The polarization of global container flows by interoceanic canals: geographic coverage and network vulnerability. *Maritime Policy & Management*. 2016;**43**(2):242–60.
36. Wang N, Wu N, Dong L-l et al. A study of the temporal robustness of the growing global container-shipping network. *Scientific Reports*. 2016;**6**(1):34217.
37. Calatayud A, Mangan J, Palacin R. Vulnerability of international freight flows to shipping network disruptions: A multiplex network perspective. *Transportation Research Part E-Logistics and Transportation Review*. 2017;**108**:195–208.
38. Liu H, Tian Z, Huang A et al. Analysis of vulnerabilities in maritime supply chains. *Reliability Engineering & System Safety*. 2018;**169**:475–84.
39. Fang Z, Yu H, Lu F et al. Maritime network dynamics before and after international events. *Journal of Geographical Sciences*. 2018;**28**(7):937–56.
40. Wu D, Wang N, Yu A et al. Vulnerability analysis of global container shipping liner network based on main channel disruption. *Maritime Policy & Management*. 2019;**46**(4):394–409.
41. Rousset L, Ducruet C. Disruptions in Spatial Networks: a Comparative Study of Major Shocks Affecting Ports and Shipping Patterns. *Networks & Spatial Economics*. 2020;**20**(2):423–47.
42. Mou N, Sun S, Yang T et al. Assessment of the Resilience of a Complex Network for Crude Oil Transportation on the Maritime Silk Road. *IEEE Access*. 2020;**8**:181311–25.
43. Wan C, Zhao Y, Zhang D et al. Identifying important ports in maritime container shipping networks along the Maritime Silk Road. *Ocean & Coastal Management*. 2021;**211**: 105738.
44. Wan C, Tao J, Yang Z et al. Evaluating recovery strategies for the disruptions in liner shipping networks: a resilience approach. *International Journal of Logistics Management*. 2022;**33**(2): 389–409.
45. He Y, Yang Y, Wang M et al. Resilience Analysis of Container Port Shipping Network Structure: The Case of China. *Sustainability*. 2022;**14**(15):9489.
46. Xu X, Zhu Y, Xu M et al. Vulnerability analysis of the global liner shipping network: from static structure to cascading failure dynamics. *Ocean & Coastal Management*. 2022;**229**: 106325.
47. Yang Y, Liu W. Resilience Analysis of Maritime Silk Road Shipping Network Structure under Disruption Simulation. *Journal of Marine Science and Engineering*. 2022;**10**(5):617.
48. Zarghami SA, Dumrak J. Unearthing vulnerability of supply provision in logistics networks to the black swan events: Applications of entropy theory and network analysis. *Reliability Engineering & System Safety*. 2021;**215**:107798.

49. Zhang C, Xu X, Dui H. Resilience Measure of Network Systems by Node and Edge Indicators. *Reliability Engineering & System Safety*. 2020;**202**:107035.
50. Asadabadi A, Miller-Hooks E. Maritime port network resiliency and reliability through co-opetition. *Transportation Research Part E: Logistics and Transportation Review*. 2020;**137**: 101916.
51. Jiang L, Jia Y, Zhang C et al. Analysis of topology and routing strategy of container shipping network on "Maritime Silk Road". *Sustainable Computing-Informatics & Systems*. 2019;**21**: 72–79.
52. Wu J, Zhang D, Wan C et al. Novel Approach for Comprehensive Centrality Assessment of Ports along the Maritime Silk Road. *Transportation Research Record*. 2019;**2673**(9): 461–70.
53. Viljoen NM, Joubert JW. The vulnerability of the global container shipping network to targeted link disruption. *Physica a-Statistical Mechanics and Its Applications*. 2016;**462**:396–409.
54. Mina M, Messier C, Duveneck M et al. Network analysis can guide resilience-based management in forest landscapes under global change. *Ecological Applications*. 2021;**31**(1):e2221.
55. Wang Y, Zhan J, Xu X et al. Measuring the resilience of an airport network. *Chinese Journal of Aeronautics*. 2019;**32**(12): 2694–705.
56. Peng P, Cheng S, Chen J et al. A fine-grained perspective on the robustness of global cargo ship transportation networks. *Journal of Geographical Sciences*. 2018;**28**(7):881–899.
57. Guo J, Wang S, Wang D et al. Spatial structural pattern and vulnerability of China-Japan-Korea shipping network. *Chinese Geographical Science*. 2017;**27**(5):697–708.
58. Ducruet C. Port specialization and connectivity in the global maritime network. *Maritime Policy & Management*. 2022;**49**(1):1–17.
59. Hu ZH, Liu CJ, Tae-Woo Lee P. Analyzing Interactions between Japanese Ports and the Maritime Silk Road Based on Complex Networks. *Complexity*. 2020;**2020**:3769307.
60. Mou N, Ren H, Zheng Y et al. Traffic Inequality and Relations in Maritime Silk Road: A Network Flow Analysis. *ISPRS International Journal of Geo-Information*[Internet]. 2021; **10**(1):40.
61. Fremont A. Global maritime networks: The case of Maersk. *Journal of Transport Geography*. 2007;**15**(6):431–42.
62. Zeng Q, Wang GWY, Qu C et al. Impact of the Carat Canal on the evolution of hub ports under China's Belt and Road initiative. *Transportation Research Part E: Logistics and Transportation Review*. 2018;**117**:96–107.
63. Fang Y-P, Pedroni N, Zio E. Resilience-based component importance measures for critical infrastructure network systems. *IEEE Transactions on Reliability*. 2016;**65**(2):502–12.
64. Dui H, Si S, Yam RCM. A cost-based integrated importance measure of system components for preventive maintenance. *Reliability Engineering & System Safety*. 2017;**168**:98–104.
65. Dui H, Zheng X, Wu S. Resilience analysis of maritime transportation systems based on importance measures. *Reliability Engineering & System Safety*. 2021;**209**(6):107461.
66. Chen H, Lam JSL, Liu N. Strategic investment in enhancing port–hinterland container transportation network resilience: A network game theory approach. *Transportation Research Part B: Methodological*. 2018;**111**:83–112.
67. Jiang M, Lu J, Qu Z et al. Port vulnerability assessment from a supply Chain perspective. *Ocean & Coastal Management*. 2021;**213**:105851.
68. Li W, Asadabadi A, Miller-Hooks E. Enhancing resilience through port coalitions in maritime freight networks. *Transportation Research Part A: Policy and Practice*. 2022;**157**:1–23.
69. Rožić T, Naletina D, Zając M. Volatile Freight Rates in Maritime Container Industry in Times of Crises. *Applied Sciences*. 2022; **12**(17): 8452.
70. Dirzka C, Acciaro M. Global shipping network dynamics during the COVID-19 pandemic's initial phases. *Journal of Transport Geography*. 2022;**99**:103265.
71. Gu B, Liu J. COVID-19 pandemic, port congestion, and air quality: Evidence from China. *Ocean & Coastal Management*. 2023;**235**:106497.
72. Pitschner S. Supply chain disruptions and labor shortages: COVID in perspective. *Economics Letters*. 2022;**221**:110895.
73. Kuźmicz KA. Impact of the COVID-19 Pandemic Disruptions on Container Transport. *Engineering Management in Production and Services*. 2022;**14**(2):106–15.
74. Cullinane K, Haralambides H. Global trends in maritime and port economics: the COVID-19 pandemic and beyond. *Maritime Economics & Logistics*. 2021;**23**(3):369–80.
75. Notteboom T, Pallis T, Rodrigue J-P. Disruptions and resilience in global container shipping and ports: the COVID-19 pandemic versus the 2008-2009 financial crisis. *Maritime Economics & Logistics*. 2021;**23**(2):179–210.
76. Liu J, Jiang X, Huang W et al. A novel approach for navigational safety evaluation of inland waterway ships under uncertain environment. *Transportation Safety and Environment*. 2022;**4**(1):tdab029.
77. Fu S, Zhang Y, Zhang M et al. An object-oriented Bayesian network model for the quantitative risk assessment of navigational accidents in ice-covered Arctic waters. *Reliability Engineering & System Safety*. 2023;**238**:109459.
78. Fu S, Yu Y, Chen J et al. A framework for quantitative analysis of the causation of grounding accidents in arctic shipping. *Reliability Engineering & System Safety*. 2022;**226**:108706.

Received: September 16, 2023. **Revised:** December 11, 2023. **Accepted:** March 4, 2024