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ORIGINAL ARTICLE

A framework for understanding reliability in container shipping networks

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Abstract

Improving reliability is increasingly regarded as an important topic in maritime transportation, especially given the significant impact that both uncertainty and delays in shipping and at ports have on the efficient flow of freight along wider supply chains. The term 'reliability' appears in different academic fields and with a variety of different meanings and interpretations. In transportation, reliability has been studied in most modes, but less so in the case of maritime containerisation. This paper reports on a systematic literature review of the concept of reliability in transportation, with a focus on reliability in container shipping networks. The selected papers were analysed to extract information according to the three identified sub-networks: (1) ports, including studies with a focus on infrastructure, service availability and risks in ports and hinterlands; (2) network structures, including the configuration of the networks, the vulnerability and resilience of the existing networks; (3) supply chains, including connectivity and planning of activities that integrate stakeholders within the supply chain. These sub-networks were then used to further query the database, searching for papers relevant to the research problem. Two research questions are addressed: (1) How is reliability best understood in the context of container shipping networks? (2) What are the determinants that affect container shipping network reliability? The review showed that there is no uniform definition of reliability in container shipping networks, but different approaches to understand it, depending on the theoretical perspective, have been adopted. Influencing factors and relevant metrics are discussed and a framework combining different dimensions of reliability, expressed as three themes, i.e., infrastructure reliability, network configuration reliability, and connectivity reliability, is developed. This can help both practitioners and researchers to understand in more detail the various dimensions and nuances of reliability specifically in the context of container shipping, its interrelationship with wider logistics systems and how, where possible, reliability can be improved.

Keywords Reliability · Maritime networks · Container shipping · Logistics · Systematic literature review

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1 Introduction

Container transportation has contributed significantly to the development of international trade and global supply chains, now accounting for more than 60% of world seaborne trade value (UNCTAD 2021). Figure 1 illustrates the remarkable growth in container TEUs that has occurred since the mid-1990s. Despite the decrease in maritime trade caused by the impact of COVID-19, container trade volumes were not significantly affected and had rebounded by the end of 2020 (UNCTAD 2021).

Container shipping is however sensitive to many influencing factors and unexpected disruptions thus reducing its reliability, the most obvious being the recent impact of the aforementioned COVID-19 pandemic. Container shipping volumes, port throughput, and operations and management of supply chains in severely affected areas all experienced interference to varying degrees as a result of the pandemic. For example in May 2021, the port of Yantian in China closed for a month due to the pandemic. The maritime sector faces other disruptions too, e.g., the blockage of the Suez Canal in March 2021 by the containership *Ever Given* had a major impact on global freight flows. When disruption happens in one part of the container shipping network, this has knock-on effects elsewhere in the network. Meanwhile, as an important sign of container shipping reliability, containership schedule reliability dropped to 35.6% in July 2022 (from 75.3% in July 2021) according to analysis from Statista (2022). It has been estimated that each additional day of delay before a shipment sails to its foreign destination will reduce the possibility of it being traded by 1% (6% when it is time-sensitive) and reduce its value by 0.8% (Djankov et al. 2010). Such delays also make trade movements erratic and unpredictable (Haralambides 2019). In this context, improving reliability is increasingly regarded as an important and fundamental topic in maritime transport, both to mitigate and overcome potential barriers and to support the operation of transport networks (AbuAlhaol et al. 2018).

Reliability has long been a question of great interest in a wide range of fields. Based on the method of Ducruet (2020), we counted the total number of network reliability-related publications in different transport modes between 1950 and 2020 identified by Google Scholar (Table 1): maritime network reliability-related analysis has still remained in the shadow of analysis on other transport networks (4.2% of total publications) but has increased in the last decade.

According to the Oxford Dictionary, reliability refers to “the quality of being trustworthy or of performing consistently well”. In the transport network field, Soza-Parra et al. (2019) defined reliability as the variability of service level when making the same trip on different days. More specifically, there is a framework agreed upon by many researchers for understanding reliability in the context of transport networks, based on three themes: connectivity reliability, time reliability and capacity reliability (Sánchez-Silva et al. 2005; Heydecker et al. 2007; Chen et al. 2011)—however this framework is less applicable in the context of shipping networks.

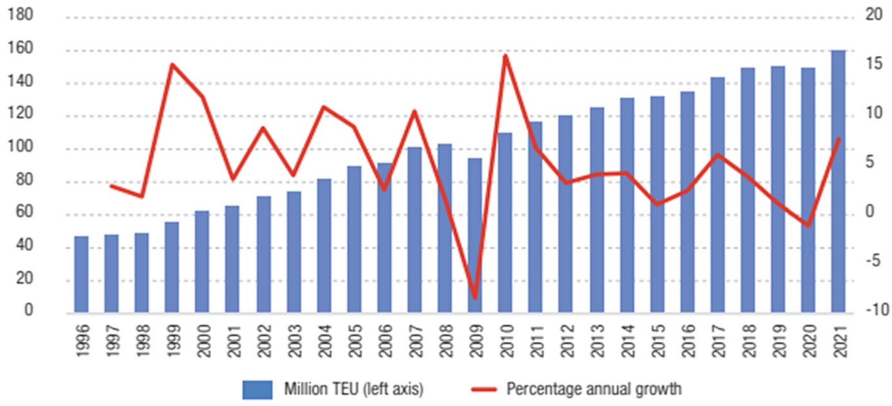

Fig. 1 Global containerised trade, 1996–2021 (million TEU and percentage annual change). *Source* (UNCTAD 2021)

The literature shows that the word reliability has often appeared in different aspects of maritime transportation and is explained by giving it a variety of meanings. The commercial indices that are currently used to analyse the reliability of container shipping networks are mainly focused on schedule reliability e.g., The Global Liner Performance (GLP) report developed by Sea-Intelligence Maritime Analysis. Schedule reliability is one of the most widely used definitions for shipping companies and their customers (Tierney et al. 2019), and also a key measure in transportation reliability analysis which has been widely studied in passenger transport. Another area of increasing interest in the context of shipping reliability is from the perspective of network structure, which is concerned with investigating the failure of different components of the network related to infrastructure and operations (Stathopoulos and Tsekeris 2003). Similarly with network reliability, Prabhu Gaonkar et al. (2011) explained reliability as maritime transportation system safety which is related to ‘risk, ambiguity and imprecision’ of the operations. Mokashi et al. (2002) defined reliability as the maintenance function of maritime transportation. UNCTAD (2019) have highlighted different aspects and interpretations of reliability in container shipping, including reliable direct connections to foreign markets, infrastructure reliability, and reliable shipping services, by enhancing the protection of ports, port efficiency, geopolitical flashpoints, trade protection, etc.

While various explanations and interpretations of reliability are provided in different fields, few studies have investigated reliability in any systematic way in container shipping networks. Therefore, this paper seeks to address this gap by providing a systematic review of the literature and answering the following two research questions: (1) How is reliability best understood in the context of container shipping networks? (2) What are the determinants that affect container shipping network reliability?

This paper is organised as follows: Sect. 2 details the methodology employed and presents the results of a systematic literature review on the topic of how reliability in container shipping networks can be best understood. Section 3 provides a framework

Table 1 Number of publications on transport network reliability, 1950–2020. *Source* Own elaboration based on Google Scholar

Type of network reliability	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
Airline/air	7	23	60	94	238	748	2240
Maritime/shipping	1	0	4	13	35	302	1560
Rail/railway	15	85	256	498	1320	5830	16,400
Road/highway	31	163	562	1130	3720	15,200	16,900
Total	54	271	882	1735	5313	22,080	37,100
%Maritime/shipping of total	1.9	0	0.45	0.75	0.66	1.37	4.2

for understanding network reliability comprising three themes synthesised from the review of the literature. Section 4 summarises the research and concludes the paper.

2 Methodology

As noted above, container shipping is sensitive to many influencing factors and unexpected disruptions thus reducing its reliability which in turn impacts the efficient flow of freight along wider supply chains. To comprehensively explore the concept of reliability in container shipping networks, the systematic literature review (SLR) technique was employed. A SLR allows the researcher to analyse and interpret the literature in a thorough and unbiased manner, enabling them to explore and summarise the body of knowledge from different perspectives on the topic (Tranfield et al. 2003; Wang and Notteboom 2014). This is particularly relevant to the purpose of this paper. Through an SLR, the paper will explore the topic from different perspectives, summarise knowledge, and develop a framework to better understand it.

According to Denyer and Tranfield (2009) and Calatayud et al. (2016), the SLR approach comprises five stages which this paper has followed: (I) formulate questions; (II) exhaustive literature research; (III) choose and evaluate the studies; (IV) research analysis and synthesis; (V) report the results. In stage (I), our research questions were formulated: how can reliability in container shipping networks be better understood and defined and what are the influencing factors?

In stage (II) the literature was searched by querying the dataset Scopus, one of the largest repositories of academic papers. Literature research in the second stage comprised four distinct phases (Fig. 2):

Phase 1 Using the keywords ("'reliability'') AND ("shipping network'' OR "maritime network'').

A keyword search was performed in papers and conference proceedings published between 1998—the earliest available year in the dataset—and 2020. The search resulted in 122 papers. As the focus of our research was to investigate reliability in container shipping networks (often referred to as 'liner' networks), in the first phase of the search we first used the keywords *container* and *liner*. However, the words (''reliability'') AND (''container shipping network'' OR ''container maritime network'') resulted in 6 papers only, while (''reliability'') AND (''liner shipping network'' OR ''liner maritime network'') resulted in 3 papers. The results showed that the number of papers was not enough to extract information and support the subsequent analysis which also proved there is little research considering reliability specifically in the context of container shipping networks. In any event, these papers were already included in the 122 papers selected above. Based on these reasons, the result of the first phase was shown as 122 papers.

Phase 2 Papers were chosen and evaluated.

The 122 articles were first evaluated according to their relevance to the research questions based on their abstract and keywords. Then quality of the papers were evaluated using the Critical Appraisal Skills Program (CASP) checklist (Wang and Notteboom 2014; Calatayud et al. 2016). The evaluation resulted

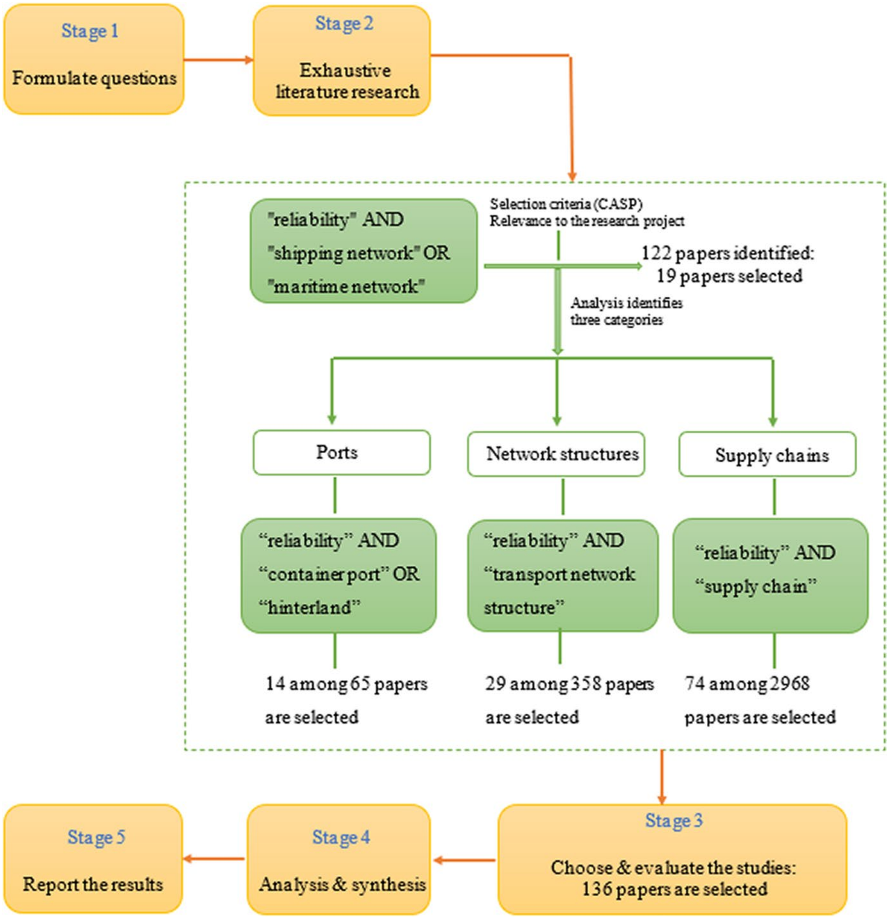

Fig. 2 Flow of the systematic review

in 19 relevant studies. The earliest article identified was published in 1998, with relevant publications growing rapidly since 2014.

From the perspective of network analysis, the container shipping network is composed of nodes which refer to ports and links which refer to the shipping routes that directly connect ports (Barabasi 2014; Ducruet 2017). With the development of the global economy, integration of logistics services and advances in information technology, container shipping is expanding its services from its core business of port-to-port transport to "door-to-door," and the container shipping network has become the backbone of logistics networks (Paridaens and Notteboom 2022; Gülmez et al. 2023). In agreement with the broad concept of the shipping network and the aim of understanding reliability systematically, we have considered it appropriate to analyse multi-scale hierarchical networks comprehensively by classifying sub-networks within the entire container shipping network.

The first sub-network is ports, with critical infrastructure assets located in the port domain. The second sub-network is network structures which are schematised as ports (nodes) and shipping lines (links). The third sub-network is supply chains which covers the transport networks used to connect consignors with consignees. The combination of these three sub-networks is hereafter regarded as the container shipping network (Verschuur et al. 2022).

The selected papers were analysed to extract information according to the three identified sub-networks: (1) ports, including studies with a focus on infrastructure, service availability and risks in ports and hinterlands; (2) network structures, including the configuration of the networks, the vulnerability and resilience of the existing networks; (3) supply chains, including connectivity and planning of activities that integrate stakeholders within the supply chain. These sub-networks were then used to further query the database, searching for papers relevant to the research problem.

Phase 3 & Phase 4: Searching and evaluating papers in the three sub-networks.

The Scopus database was further queried using keywords relevant to the three sub-networks. Papers were then evaluated and selected based on their relevance to the research and to the selection criteria (CASP) approach (employed previously in Phase 2). The use of the keywords ("reliability") AND ("container port" OR "hinterland") to select articles in the ports category resulted in 65 articles among which 14 were selected. Then, using the keywords ("reliability") AND ("transport network structure"), resulted in 358 articles, among which 29 satisfied the selection criteria. Finally, using the keywords ("reliability") AND ("supply chain") resulted in 2,698 articles, among which 74 were selected. After the four phases of the literature research, a total of 136 articles were ultimately selected; due to space constraints we cite most, but not all, of these articles in this paper.

3 Discussion

Following on from the thematic analysis, reliability in container shipping networks can be generally defined as *the ability to perform on-time container services under uncertainty*. In addition, the three *sub-networks* identified in the thematic analysis are now reconceptualised as three *themes* for further investigation: (1) Infrastructure reliability: reliability was defined as the availability, capacity and efficiency of infrastructure in shipping networks (discussed further in Sect. 3.1); (2) Network configuration reliability: reliability here refers to whether the network could be affected by disruptions or risks and the ability of the network to perform well even when parts of the network have failed (Sect. 3.2); and (3) Connectivity reliability: reliability defined according to the integration of different stakeholders along supply chains (Sect. 3.3).

Figure 3 illustrates the three themes and constitutes a framework for understanding reliability in container shipping networks. The bubbles refer to the identified themes and the bullet points refer to the influencing factors that could affect the reliability of the networks within each theme. The overlapping areas of the bubbles show that some of the literature was multi-disciplinary, one factor could affect

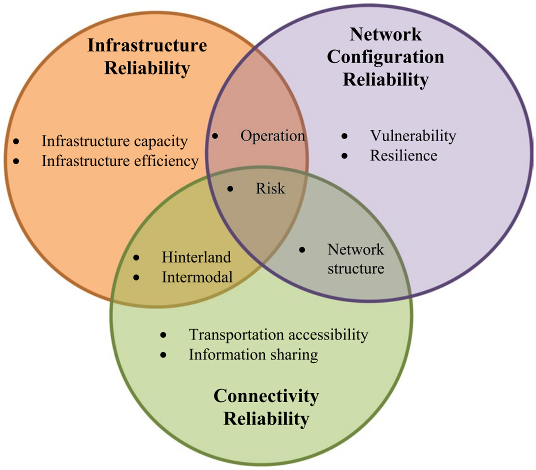

Fig. 3 A framework for reliability in the context of container shipping network

the reliability of more than one theme but from different perspectives. For example, papers under infrastructure reliability and connectivity reliability both pointed to hinterland related issues, one analysed it from the perspective of hinterland construction and the other from the perspective of integrated transport systems.

Few papers however have provided a systematic analysis of reliability from the perspective of more than one theme, and our framework sought to comprehensively and systematically address this deficit. Our framework comprising the three themes and their influencing factors is discussed in the sections that follow.

3.1 Infrastructure reliability

As noted in Sect. 1 above transport network reliability can be defined according to infrastructure availability and capacity, focusing on the physical properties of the network. In container transportation, reliability can be defined according to the availability, efficiency and capacity of the infrastructures and services that container shipping networks provide. Literature on this theme has relied on the analysis of reliability in accordance with port time and container shipping schedules (Notteboom 2006; Sun et al. 2018). For example, some papers point to the role of port capacity and infrastructure occupancy (Dekker et al. 2011; Novaes et al. 2012) where reliability is usually defined according to how long a vessel needs to wait for a berth (Balliauw et al. 2019). Although there are many other influencing factors that can lead to longer port times, in the long run the reliability of the container shipping network is still driven by structural factors (UNCTAD 2021) including infrastructure, service and trade facilitation. According to the dataset "Global Transport Costs Dataset for International Trade" (GTCDIT), significant structural improvements in ports could reduce maritime transport costs by around four per cent.

Besides the physical infrastructure availability and capacity, studies have also considered the performance efficiency of ports including port planning and infrastructure efficiency. From the perspective of port planning, researchers have emphasised the berth allocation problem, quay crane assignment problem, the effect of human factors, port call optimisation etc. (Moon and Woo 2014; Comtois et al. 2018; Martínez-Pardo et al. 2018).

In addition to the availability of port infrastructure, part of the literature has applied a broader concept of infrastructure reliability which emphasises the importance of transport services and the availability of hinterland infrastructure. Under this broader concept of reliability, studies highlight dry (i.e., inland) ports (Lättilä et al. 2013; Facchini et al. 2020; Jiang et al. 2020) which can reduce congestion and emissions. Other studies point to the role of intermodal connections and cooperation among seaports and dry ports (Bärthel and Woxenius 2004; De Langen and Sharypova 2013) and integration of different transport services along the supply chain (Song and Panayides 2008; Woo et al. 2013).

Ports are very exposed to climate-related events such as sea-level rise and flooding, strong winds and changes in storm patterns. These impacts materialise as direct damage to the physical infrastructure system located within the port boundaries. This increases the risk of delays or port closure, resulting in significant economic costs, with adverse effects on container shipping reliability. Besides climate-related events, other unexpected disruptions (e.g., COVID-19) can also affect port operations and vessel turnaround time. Unpredictable risks affecting the operations of port infrastructure increase the waiting time and operations time, decrease the reliability of the port and propagate to the entire container shipping network. Infrastructure reliability in the context of container shipping networks thus calls for a complex infrastructure system to be designed and operated in a manner that can exhibit efficiency and also robustness in response to risks (Nguyen et al. 2021). In port infrastructure systems, the process of assessing reliability includes the identification of risks associated with the infrastructure and the development of plans that enable systems to maintain functionality (Mutombo and Ölçer 2017; Romero-Faz and Camarero-Orive 2017). Traditional risk analyses—usually based on critical infrastructure failure—often do not incorporate risk in port areas and the inter-dependencies of assets (Verschuur et al. 2022). Recent studies have also begun to consider the wider infrastructure network e.g., the risks in the hinterland and the knock-on effects to other network components (Thacker et al. 2017; Sriver et al. 2018).

In addition to considerations around physical infrastructure, recent studies on reliable port infrastructure systems have pointed to digital applications for risk management. The concept of the "smart port" has become an important topic in the maritime field. Ports nowadays not only provide basic logistics and transport services but also value-added services, trying to reduce dependency on human resources and use smart applications and sustainable technology to improve efficiency and reduce emissions (Yau et al. 2020). The literature identifies three aspects of smart ports linked to reliability: (i) information systems which help to reduce dependence on physical documents and improve the reliability of the network by enhancing data security and providing a fast and easy flow of information (Shuo et al. 2017; Rajabi et al. 2019); (ii) smart applications in port operations which help to optimise resource allocation and reduce turnaround time and congestion (Cho et al. 2018);

and (iii) efforts around reducing the environmental impact of ports (Douaioui et al. 2018; Molavi et al. 2020).

This theme included publications discussing infrastructure in the port and hinterland. Reliability may be affected by infrastructure capacity, efficiency, operation ability, connections between hinterland and port, and risk management. The identified factors within infrastructure reliability are summarised in Table 2.

3.2 Network configuration reliability

The evolution of container shipping networks, and in particular the development of hub and spoke network structures, has led to a new set of risks in the connected shipping network (Calatayud et al. 2017). Examples include the impact of the Fukushima nuclear disaster which closed the ports of Yokohama and Tokyo in 2011 and the bankruptcy of Hanjin Shipping which has had significant knock-on impacts in 2016. The potential disturbances to container shipping networks include many natural and human factors: port worker strikes, terrorist attacks, cybersecurity threats, regulatory barriers, changes in shipping companies' strategies, piracy, marine accidents, natural disasters, adverse weather conditions, etc. These in turn can cause congestion, service deviation, stoppages, or the complete failure of the supply chain (Tang and Nurmaya Musa 2011; Gurning et al. 2013; Huang et al. 2022).

Studies on network reliability are numerous and concern *inter alia* network robustness, adaptability, preparedness, vulnerability and resilience. While some of the definitions of network reliability used are similar, reliability is analysed and explained from various aspects to address different requirements (Wan et al. 2018). The majority of the research pertaining to this theme defines reliability from the perspective of network capability (e.g. to withstand or adjust to disruption), which in turn arises from its inherent configuration, with the literature in particular pointing to two aspects namely vulnerability and resilience.

Vulnerability can be defined as the degree to which a system will suffer an adverse impact when a disaster event occurs (Sánchez-Silva et al. 2005). Resilience can be regarded as a system's ability to resume normal operations after sustaining unfavourable conditions (Wan et al. 2020). Resilience and vulnerability refer to the ability of a system to respond to various internal and external disruptions and shocks, with some debate as to whether the two concepts are fundamentally the same. It is generally agreed that resilience is more focused on the system's ability to respond and recover after an event, while vulnerability mainly refers to the inherent attributes of the system before the event, and describes the possible scenarios of system interruption (Berdica 2002; Berle et al. 2011). The difference between vulnerability and resilience reflects two ways of understanding reliability. One regards reliability as the stability of the shipping network, the other refers to the dynamic ability of the latter to transform from one equilibrium state to another (Wan et al. 2018). In practice, some of the research has focused on the influencing factors that are related to the configuration of the shipping network e.g., determining its important nodes and edges (Miller-Hooks et al. 2012; Lhomme 2016; Wu et al. 2019a, b). Some studies investigate the shipping schedule rerouting problem after a disaster event that led to

Table 2 Summary of three themes and influencing factors

Theme	Definition	Influencing factors	Key references	Main focus regarding reliability
Infrastructure reliability	Availability, efficiency and capacity of the transport infrastructures in ports and supply chains	Infrastructure capacity	Dekker et al. (2011), Balliauw et al. (2019)	Port infrastructure dictates vessels turnaround time and waiting time in port which is highly related to the time reliability of container vessels
		Infrastructure efficiency	Cho et al. (2018), Yau et al. (2020)	
		Operation ability	Notteboom (2006), Moon and Woo (2014)	
		Hinterland construction	Lättilä et al. (2013), Facchini et al. (2020)	Infrastructure reliability in port-related assets, considering inter-dependency from the perspective of connection in port
		Intermodal connection with hinterland	Bärthel and Woxenius (2004), De Langen and Sharypova (2013)	
		Infrastructure risks	Mutombo and Ölçer (2017), Verschuur et al. (2022)	Reliability is determined not only by port infrastructure construction but also the pre-disaster investments to increase their reliability in the context of the range of potential disruption events
Network configuration reliability	Whether the network is easily affected by disruptions and the ability of the system to perform well even when parts of the system have failed	Vulnerability	Calatayud et.al. (2017), Wu et al. (2019a, b)	The degree to which a system will have an adverse impact when a disaster event occurs
		Resilience	Yuan et al. (2019), Asadabadi and Miller-Hooks (2020)	A system's ability to resume normal operations after sustaining unfavourable conditions, e.g. reroute and backup ports
		Network structure	An et al. (2015), Mohammadi et al. (2019)	Network reliability can be improved by considering node failure potential during the network design stage

Table 2 (continued)

Theme	Definition	Influencing factors	Key references	Main focus regarding reliability
Connectivity reliability	The probability of the components in the networks being connected	Transportation accessibility	Stathopoulos and Tsekeris (2003), Calatayud et al. (2016)	The degree to which nodes in the shipping network are connected especially when links fail
		Integrated transport system	Lam and Gu (2013), Khaslavskaya and Roso (2020)	The connectivity reliability of the supply chain depends on the coordination across different transport modes and systems
		Information sharing	Song and Panayides (2008), Zacharia et al. (2011), Woo et al. (2013)	Connectivity reliability refers to the collaborative linkage and interaction of partners up and down the supply chain (trade procedures, integration degree, visibility, and information sharing)

port capacity reduction (Kashiha et al. 2016; Yuan et al. 2019). In order to provide sufficient service even when parts of the network have failed, network structure optimisation studies also consider the role of backup ports and alternative route designs under disruptions (An et al. 2015; Asadabadi and Miller-Hooks 2018).

From the perspective of network configuration, the term *reliability* is defined by whether the network could be affected by the disruptions and the ability of the system to perform well even when parts of the system have failed (Snyder and Daskin 2005). Important in this context is then the question as to whether the network has the capability to still provide sufficient operational functionality and in turn the ability to recover from disruptions.

Network analysis is a method frequently used in analysing reliability, in the case of air (Lordan et al. 2014), road (Sienkiewicz and Hołyst 2005), rail (Li and Cai 2007) and maritime transport (Kaluza et al. 2010; Ducruet and Zaidi 2012). Network analysis helps to build the network configuration and captures the maritime network behaviour topologically (Lhomme 2016) using metrics such as network degree, average path length, clustering coefficient, centrality and more (Wu et al. 2019a, b). Indeed, network analysis and graph theory have also been applied to study the vulnerability and robustness of the network by simulating attacks on it. The intention is to show the impact of disruption especially on the key nodes of the network (Calatayud et al. 2017; Wu et al. 2019a, b).

Research in a number of disciplines has contributed with advances in network reliability and network structures, especially regarding the selection of hub location. In hub location studies, the aim is to find suitable locations for hubs while optimising a cost-based or service-based objective (Aversa et al. 2005; Gelareh and Nickel 2011; Azizi 2019). However, nearly all hub location studies have assumed that the chosen hubs would always operate functionally as planned, with the network designed for perfect conditions (An et al. 2015). In practice of course hubs could fail for a variety of reasons (Mohammadi et al. 2019).

Improving reliability requires stakeholders to try and estimate when the disruption will occur and how long the effects will last before the network can again operate as usual (Liu et al. 2018). Mitigating the impact of disruption can be best achieved by a combination of improved network design and strengthened emergency response and recovery capabilities [e.g., a network's ability to absorb disturbances in time before the interruption occurs, adapt to changes after the interruption, and recover quickly (Carvalho et al. 2012)]. In accordance with the preceding discussion, the identified factors within the network configuration theme can be summarised as network vulnerability, resilience and network structure (Table 2).

3.3 Connectivity reliability

As noted in Sect. 1 above, connectivity has been regarded as one of the determinants when assessing the reliability of transport networks. The relationship between reliability and connectivity can be derived from the concept of the network, which is concerned with the probability of components in the network being connected (Bell 2000). The literature reviewed in Sects. 3.1 and 3.2 focused on container shipping networks and the interface between ports and shipping, but not the interface with stakeholders of the supply chain. The literature on connectivity reliability can be divided into two parts due to different influencing factors: transport engineering and supply chain management. The former refers to the connectivity between transport modes and services to ease time and cost. The latter refers to the integration among partners across the supply chain to achieve better performance.

The concept of connectivity from the perspective of transport engineering is defined as the degree to which nodes in the shipping network are connected (Notteboom 2006; Calatayud et al. 2016) or, more specifically, as the degree to which ships can reach a given destination when links fail. The failure of different components of the network, related to both infrastructure and services, may have diverse impacts on network performance. Studies consider different variables to estimate connectivity between nodes in a given network configuration, e.g., by assessing the availability and capacity of transport services (Salleh et al. 2019), the transfer time, waiting time, tariffs and service connection ability for transhipment (Sun et al. 2018), direct links between two ports, number of port calls (Ducruet and Zaidi 2012), etc.

The literature also considers the connectivity between different modes and systems, i.e., coordination between modes and integration of services (Burghouwt and Redondi 2013). A large body of literature has focused, for example, on intermodal connectivity such as road-rail, port-road and port-rail, and other available intermodal possibilities (Wilmsmeier et al. 2011; Lam and Gu 2013; Wang et al. 2016; Khaslavskaya and Roso 2020). To enhance interoperability across transport modes, a broader concept—*integrated transport systems*—has become a topic of interest in maritime transport research. According to the ITF (2012), integrated transport systems integrate different transport domains including infrastructure, services, policies and information with the aim of maximizing connections among all shipping-related aspects at different levels. In line with the emergence of a better and seamlessly connected shipping network, studies on infrastructure reliability also consider how to maximize coordination, e.g., the inter-dependency of port infrastructures and connections between port and hinterland as discussed in Sect. 3.1.

From the perspective of supply chain management, the term *connectivity reliability* is defined as the collaboration of partners upstream and downstream in the supply chain (Fawcett et al. 2007), relating to information sharing among stakeholders and the interactions among firms. The measurement of connectivity reliability involves both the infrastructure and the behavioural responses of the users (Bell 2000). The impact of disruptions depends on how well the stakeholders can adapt. For example Sect. 3.2 (network resilience) considered whether there might be an alternative route or backup ports and if they could respond quickly with spare capacity. In such a case, the reliability of the shipping network will increase when facing disruptions. The state of network information-sharing and technological advances play an important role in determining the impact of a disruption. Zacharia et al. (2011) found that information connectivity reliability was beneficial to both upstream and downstream stakeholders and in the context of container shipping the adoption of such technologies contributes to communications with shipping lines and ports (Calatayud et al. 2016).

Collaboration on information-sharing through the supply chain offers insights to another research stream – the integration of the supply chain. The higher the degree of integration, the better a supply chain performs (Song and Panayides 2008). The presence of technology and information-sharing is crucial in facilitating integration across stakeholders in the supply chain (Wang et al. 2017; Liu et al. 2018). Woo (2013) suggested that the integration between ports and supply chains can reduce the order cycle time and build a more flexible system. The use of connectivity reliability is beneficial in communicating with shipping lines and in increasing efficiency in ports. This is also highlighted by the evidence from smart port considerations (Sect. 3.1).

In the context of connectivity, network reliability may be affected by the accessibility of nodes in the network and the connection between transport modes (from the perspective of transport engineering), and information sharing and integration of firms (from the perspective of supply chain management). The identified factors in connectivity reliability are summarised in Table 2.

3.4 Other factors

Two further factors were identified in the systematic literature review but they do not sit easily within the framework/three themes (Fig. 3) because of their indirect connection to reliability and untested impact. Nonetheless, they are introduced and discussed below.

3.4.1 Freight rates uncertainty

In May 2017, severe port congestion occurred in Shanghai Port, with congestion following soon after at Qingdao Port and Ningbo Port. Xu (2017) suggested that one of the reasons for this serious congestion were rumours that freight rates, after 1 May 2017, were expected to rise sharply. Many shippers thus increased their volumes to avoid the anticipated rises in freight rates. There is a large body of literature modelling freight rates and their influencing factors (Xu et al. 2011; Kou et al. 2018). Several studies have highlighted important aspects of service quality that may affect freight rates, apart from supply and demand, such as frequency of port calls, the number of direct services (Martínez-Zarzoso and Nowak-Lehmann 2007) and the role of transhipment (Wilmsmeier and Hoffmann 2008). However, there are fewer studies that analyse the relationship between freight rates and shipping network reliability. Freight rates are rarely recognised as one of the risks to the reliability of container transportation. In the face of declining rates and a difficult and unpredictable market environment, carriers have at times reorganised schedules in order to reduce capacity, introducing a series of blank, or cancelled, sailings hence disrupting regular schedules (UNCTAD 2019). Both in shipping networks and the wider supply chain, stable freight rates play an important role in network vulnerability.

3.4.2 Sustainability

As is the case in other domains, sustainability-related issues are playing a greater role in today's container shipping. The industry's high environmental impact is exacerbated by the increase in traffic volumes and an over-concentration of traffic flows in certain seaport regions (Ducruet 2017). According to the IMO's Fourth Greenhouse Gas Study (2020), CO_2 emissions from maritime transport represent a significant and growing share of total global greenhouse gas (GHG) emissions. Research so far has focused on how to reduce the environmental damage caused by maritime transportation and logistics activities without compromising the industry's economic viability (Psaraftis and Kontovas 2010; Lam and Notteboom 2014). Key foci of both regulators and industry include: energy-saving engines, efficient ship designs, increasing average vessel size, cleaner fuels, alternative fuels, improving maritime operations, etc. (Lindstad et al. 2012; Bouman et al. 2017). There is a focus too on operational measures including speed optimisation (Yin et al. 2014; Ferrari et al. 2015) and optimised routing and fleet management. It is also widely recognised that a significant share of shipping emissions can be attributed to the time spent by vessels in port. Thus, port congestion and vessel turnaround times (discussed in Sect. 3.1) can play an important role in the environmental impact of shipping. There is a growing body of literature that focuses on topics such as environmental governance in shipping and the greening of port operations (Lun 2011; Davarzani et al. 2016). As both a large-scale user and also as a carrier of energy, maritime transport needs to operate in a more sustainable way and to do so without compromising network reliability. Digitalisation tools and smart logistics advance network efficiency and resilience and also can help in this regard.

4 Conclusion

The literature detailed in this paper has highlighted how contemporary understanding and interpretations of shipping network reliability generally focus on one particular aspect, e.g., port performance. Ports are of course important nodes in container shipping networks, but reliability of other components and aspects of shipping networks can also affect the performance of container transportation. In line with this, a more comprehensive understanding of reliability in container shipping networks is required. Nonetheless, our review has shown that there is no unified or absolute definition of reliability in container shipping networks, and different approaches to understand it are taken depending upon the focus and framework of reference adopted. The literature is spread over a large spectrum of academic fields and stakeholders. It was essential, therefore, to provide a clearer overview of research motivations and highlight the differences between themes identified.

Our systematic literature review examined determinants across sub-networks (ports, network structure and supply chains) and in turn led to the development of a framework comprising three themes: (1) infrastructure reliability; (2) network configuration reliability; and (3) connectivity reliability (Fig. 3). In the framework a total of 12 influencing factors were identified, some of which are common to more than one theme. Our framework provides all stakeholders (researchers, policymakers, industry, etc.) with a holistic, and more complete than heretofore available, understanding of the many and varied influences that impact the reliability of container shipping networks.

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