Maritime traffic as a complex network: A systematic review

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Abstract

This article proposes a systematic review of papers dealing with maritime traffic whose methodology is based on a Complex Network Analysis (CNA) approach. The papers selected have been categorised, reviewed and analysed, extracting the most important characteristics of each, namely sources of information, geographical scope and network modelling characteristics, and then grouped according to the specific topics covered. The literature is classified according to two main streams: Papers dealing with a topological description of maritime networks, and papers applying a CNA approach to specific topics. In each case, an analysis is carried out, highlighting the most interesting concepts and methodologies of the selected papers, summarising the most important findings and proposing further topics for investigation. An additional analysis has been carried out with the keywords of the selected papers, creating a network and identifying seven communities representing and grouping the main research interest topics in the selected literature.

Keywords: Maritime Traffics; Complex Networks; Bibliometric analysis; Complex Networks Analysis

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1 INTRODUCTION

The significance of topological structure in transport modes in general and in maritime transport in particular has led many researchers to investigate and describe the structures and dynamics that make the transport a complex network (CN). This task may be cumbersome due to the intrinsic difficulty of understanding these structures given their dynamical complexity, the evolution of the network, and the connection diversity or node diversity (Strogatz, 2001).

Sea ports are one of the main elements of transport worldwide, acting as points that enable the flow of cargoes across global supply chains (Burns, 2018). Therefore, the maritime transport network can be understood as a complex structure composed of a set of vertices (ports) connected to each other by maritime lines (edges). Note that although this is the straightforward and most common way of modeling maritime networks, other alternatives will be commented on later.

In fact, as cargoes have an origin and destination of a quantifiable number of freights, the maritime transport network can be understood as a directed network with wheighted edges (Dorogovtsev & Mendes, 2013). This CN can be explored mathematically through well-known and studied concepts such as node degree, shortest path lengths, clustering or community structures (Boccaletti et al., 2006) that become part of the so called Complex Network Analysis (CNA) methodology.

Throughout history the maritime transport network has been of vital importance. It is possible to track the history of humanity and the centres of world power, or "geographical cores", by following the successive central nodes of this network. Within the environment of each successive central nodes of the maritime transport network, a dominant culture and civilisation have developed at each point in history (Attali, 2007). A route of this network and its successive central nodes can be traced in a journey of more than five thousand years, passing from Babylon to Singapore and Shanghai (Stopford, 2009).

The modelling of maritime traffic as a network in which ports are equivalent to network nodes and ship movements correspond to edges, has proven to be an effective tool for the representation of maritime traffic since the first documented approach more than fifty years ago (Robinson, 1968). Since then, many examples in literature prove the principle of the network model, and more specifically of the complex network, to understand maritime flows.

However, research in maritime transport is far from being as widely studied as other modes of transport, especially from a network perspective (Ducruet, 2015). Although a wide range of research work of various approaches modelling maritime traffic as a complex network exists, such work is still fragmented and it is impossible to define a common framework, which complicates their systematic review.

The explanation for the relatively small number of research works in this field has been explained by Ducruet (2015) based on five main reasons: a) Most studies have focussed on populated places, rather than on empty spaces such as the marine environment. b) The geographical distribution of maritime flows is difficult to define due to the absence of a visible track infrastructure. c) The fact that most passenger traffic has shifted to other modes of transport, such as air transport, because the second half of the twentieth century and the rise of telecommunications systems has made maritime traffic less attractive to researchers. d) The continuing reduction in shipping costs compared to other logistics costs, which forces efforts to minimise overall transport chain costs focus on other transportation modes. e) The access to reliable information sources and comprehensive statistics required for the research work of experts is costly and difficult to obtain, making research on maritime transport impossible in many cases.

Complex networks are able to capture the interaction among the entities that compose them. They evidence properties that are not obvious when considering each of the parts independently, being their networked character one of the features of the structure of these systems (Estrada, 2012). For this reason, unsurprinsingly, different modes of transport have been studied from a CN perspective in recent years. Some examples can be found when modeling urban traffic networks (Ding, et al., 2019); urban travel demand (Saberi, et al., 2018); the public transportation in Great Britain (Regt, et al., 2019) and Singapore (Soh, et al., 2010); air transportation Networks of China (Wang, et al., 2011) and US (Xu & Harriss, 2008); airline route networks (Lordan, et al., 2014); highway network structure (Deng, et al., 2010); Australian Airport Network (Hossain & Alam, 2017); rail networks (Yang, et al., 2015), (Qing, 2012) or (Ouyang, et al., 2014), among others. Other examples of the study of vulnerability in different modes of transport can be found in Cats & Jenelius (2014) for public transport networks and O'Kelly (2015) for the air transport sector.

It is worth to mentioning at this point the seminal paper by Ducruet & Beauguitte (2014) to understand how complex network research has been integrated into geography and regional science, and the use of a comprehensive review to study half a century of investigations for modeling the growth of transportation networks (Xie & Levinson, 2009).

In the case of maritime transport, as in the cases described for the other modes of transport, a complex network approach to modelling the maritime transport network can help to better understand the strengths (robustness) or weaknesses (vulnerability) of the network. Using classical CNA measures such as centrality or degree, the most important nodes of the network can be identified: for instance, the most central ones will correspond to those nodes whose elimination will make the network more vulnerable.

There is no doubt that the maritime transport in particular, rather than global transportation systems in general, can fit into this representation, and the literature published confirms this statement. In fact, we are aware of only eight review papers that in one or another perform an analysis of the published literature, reviewing generally or partially the research developed in the context of CN and maritime transportation.

The first review (Caschili & Meda, 2012) describes the main characteristics of the science of complexity and the complex adaptive systems, and farther focusses on the few studies appertaining to the global maritime network (Global Cargo Ship Network, GCSN), presenting then an overview of the main features of the GCSN based on existing literature as well as a comparison of Complex Adaptive System (CAS) features with shipping. The following year, Lin & Ban (2013) reviewed different public transport systems; analysing their complex network topology, providing a comprehensive review of topological representations, measurements and case studies of transportation systems from a complex network approach and naming the basic measures used in the researches: node centrality, degree, betweenness centrality, closeness centrality, straightness centrality, and weight and strength.

A critical review of "port geography" in the period 1950-2012 can be found (Ng, et al., 2014) detailing the most important research topics relating to "port geography" and summarising the main focus of research, including port connectedness, port selection, competition and cooperation, and a port’s position in shipping strategies and networks. It also includes, among other topics, the main research efforts regarding the role of ports in the supply chain and port-city/territory relationships that will be addressed in depth by some of the articles cited later.

Focussing on conducting a literature review to address network optimisation in container shipping routing in single and multiple periods, Tran & Haasis (2015) describe the issue of network design, laying special emphasis on the hub and spoke structure. This concept was originally created in the aviation market that at the end of the 1970s, following the deregulation of US airlines, became the main distribution model used by major international logistics companies. It is broadly based on the consolidation of large scale shipments at the principal terminals as hubs, and the redistribution of smaller scale shipments to their respective destinations through spokes (Song & Panayides, 2015).

Sislian et al. (2016) focussed their research efforts on the revision of two interrelated concepts such as port sustainability and the Ocean's Carrier Network Problem (OCNP). Papers between 1987 and 2013 were revised to improve the understanding of the sustainability of ports and study their application and potential benefits for the OCNP, concluding that the introduction of port sustainability indicators in the design process of the logistics networks is at an initial phase of development.

With a more general scope and using the methodology of systematic literature review Calatayud et al. (2016) studied concepts such as connectivity, markets and trade, in the context of transportation engineering, transport and international economics, and supply chain management. This yielded three different search domains: Transport, Supply Chain and International Trade, selecting a total of 137 relevant articles.

More recently, Ducruet (2020) made an excellent critical review of the geography of maritime networks showing that the vast majority of studies consider how these networks are constructed (topology), how they can be improved (optimisation) or interrupted (vulnerability). He uses different methods and data sources to describe the general structure of the network and the centrality of the port nodes.

Finally, we can mention the work by Woo et al. (2013) who analysed 840 papers dealing in general with port management and operation. Although this review was not in fact related to

CNA and maritime transportation, CNA was the methodology used by the authors of the review to analyses those papers. We see here how CNA can play an important role in bibliometric analysis, and in fact in our case we use it in section 4.3 as a tool for studying the relationship among the keywords in the papers reviewed.

For a specific bibliometric analysis, Lau et al. (2017) use metrics such as degree and betweenness centralities to study the co-occurrence within the word graph formed with the titles of the papers investigating the maritime transport of containers for the periods 1967-1982 and 1983-1899, as well as single linkage analysis of title words and bisecting k-means analysis of title words, for the period 1999-2013. This article made clear the need to include the keywords of the articles, as in the present manuscript, or even the abstract of the articles to analyse the full body of the papers for further research.

A literature review is a process that involves different tasks: planning, analysing, organising, drafting and redrafting (Galvan & Galvan, 2017). However, traditional literature reviews such as those previously mentioned are susceptible to bias during these tasks, although they can be valuable in some situations with limited resources or where the topic does not warrant a more detailed approach. Meanwhile, *systematic review* methodology is well defined in five steps (Denyer & Tranfield, 2009), and it is based on a clearly formulated question, identifying relevant studies, appraising their quality and summarising the evidence by use of an explicit methodology (Khan, et al., 2003). Therefore, the use of systematic reviews will be preferred to traditional reviews if researchers have the necessary resources at their disposal (Haddaway, et al., 2015).

Systematic reviews are very common in other fields of research, such as medicine in which, following the classic steps of a systematic review, all the evidence on a specific question can be retrieved, evaluated and summarised in order to later interpret all data from a critical analysis, including the possibility of conducting a meta-analysis of the data to complete the results and the understanding of the research efforts (White & Schmidt, 2005). Examples of systematic reviews from various disciplines can be found in (Gil, et al., 2020) reviewing onboard Decision Support Systems for accident prevention; (Pradana & Noche, 2019) reviewing maritime transportation optimization using linear programming; (Mele, et al., 2019) reviewing Marine Ecology and Economy for Integrated Coastal Management; (Ozturk

& Cicek, 2019) reviewing collision risk assessment in ship navigation; or (Neilson, et al., 2019) reviewing Big Data in the Transportation Domain.

In areas that include maritime transport such as supply chain management, systematic reviews have also been used to systematise existing research. In fact Durach et al. (2017) proposed a refined version of the standard procedure, with six steps instead of the classical five, recommending the retrieval of a sample of papers before performing the selection of the pertinent literature. They claim this is especially suited when there is a need to mitigate the frequently discussed gap between research and management practice, especially in supply chain studies

Therefore, the application of a systematic review is a powerful tool to improve the understanding of the research efforts carried out by performing a critical analysis and a systematised methodology that had not yet been conducted in this area. In this case the variety of papers collected in our review makes it of interest to systematise all the approaches and research efforts of the scientific community in this field.

Here, our research question is to ascertain which papers have modeled the maritime transport with a complex network approach, and how this modelisation has enabled a better understanding of the maritime transport. In our review, by synthesising and summarising the existing knowledge in the selected papers, the intention is to understand what is being done in the academy regarding maritime transport with a CN based approach, to critically observe the main topics covered by the literaure, and identify research gaps for future research topics in the field.

The rest of the paper is structured as follows: Section 2 explains the methodology of the systematic review used, including an introduction to Complex Networks concepts later discussed in the manuscript; In Section 3 the results are presented grouping the papers between those dealing with a topological description of maritime networks, and those applying a CNA approach to specific topics and problems. A CNA of both groups of papers' keywords is also icluded in this section. Finally, in Section 4 the primary results of the analysis are summarised, and research gaps and shortcomings of the selected papers presented.

2 METHODOLOGY

2.1 SYSTEMATIC REVIEW

This paper focusses on articles devoted to model maritime traffic using CNA (i.e., papers for which CNA is the main methodology applied to describe the flows), as well as on those using CNA to explain partially, i.e. as part of their objectives, a specific aspect of maritime transport (f.i., risk or vulnerability of the network). For the latter the CNA is usually used together with other methodologies that explain other research questions.

With this research papers as the target, the methodology of *systematic review* is particularly applicable. This specific procedure makes it possible to locate existing papers and select and evaluate contributions, analyse data and evaluate evidence so that conclusions can be drawn about what is and what is not known in a given scope of study.

According to this technique, a five-stage procedure will be carried out (Denyer & Tranfield, 2009; Tranfield et al., 2003), being the first step the "Question Formulation", which will guide the search to identify relevant studies. In our case the research question is "How complex networks methodology have contributed to the understanding and the modelling of maritime transport?"

Next, for the "locating studies" step, we select and compile the existing literature related to the topic. A literature search for studies that have been published in scientific journals using Scopus and Web of Science databases was performed. The search was conducted in September 2019, and the results of the process of searching and refining the selection of papers is shown in Table 1. Refining the search, excluding papers not relevant to the topic proposed such as those belonging to other fields (Environmental Science or Computer Science), and removing duplicated papers leaves a total of 120 selected papers.

--------------------------------------Table 1-------------------------------------

Once the first selection of papers has been made, the "snowballing" technique is applied (Wohlin, 2014). With the identifed search strings (see Table 1) the first set of papers are selected searching in the databases. These papers are revised and for each a *Backward*

Snowballing is performed (using the reference list of each paper to identify new papers to include) as well as a *Forward Snowballing* (identifying new papers citing the paper). The bibliography of the main authors will also be reviewed to check the possible inclusion in the set of papers. This process is iterated until no more papers are found. Papers found after the last iteration compose the final dataset of papers selected for the systematic review. In our case, after discarding unavailable or domestic papers not written in English, 97 is the final number of selected papers.

2.2 COMPLEX NETWORKS

Complex Network Analysis (CNA) is a well-known tool, able to represent real-world systems composed of entities having interactions among them. The representation is made by means of nodes, that is, the entities (f.i. a country, a port,…), and edges, that is, the representation of the interactions among them. Depending on the kind of interaction among the nodes, the edges can be directed or undirected, weighted or unweighted, as a function of the direction and intensity of the relationship. CNA modelling allows to understand how the interactions among the entities evolve.

Although it roots come from Graph Theory, the work of Barabási and Albert in the 90s was crucial showing that the random graph theory of Erdös and Rényi could not fully explain links distribution in big networks (Cohen & Havlin, 2010).

CNA has been used as well to perform a literature review analysis, building the network by the keyword co-occurrence (Choi et al., 2011), citations (García-Lillo et al., 2019) or even co-authorship (Lee et al., 2012). This technique allows for observation of the evolution of the literature review of certain topics over time, how the keywords connect among them, and also in which topics they are involved (Lozano et al., 2019).

In CNA, there are multiple metrics that help to evaluate the relative position of the nodes in the network. The number of connections from a node is called its *degree*, and the distribution of degrees in a network (exponential, power-law, …) provides an indication of the topology of the connections (Barabási & Albert, 1999; Clauset et al., 2009). *Betweenness Centrality* defines the critical nodes connecting pairs of nodes in the network.

Moreover, the graph can be divided into *communities*, that is, groups of nodes that have more interactions among them than those that could be observed in a random network by chance (Newman, 2010). In other words, groups of nodes that have more edges among them than with the rest of the network. There are multiple methods to identify communities, being the quality of each partition measured by its modularity (which compares the links inside communities with the links between communities). The procedure used in this paper is from Blondel et al. (2008) whose iterative algorithm is composed by different iterations. In each pass there is a modularity optimisation by changing the position of each node to different communities to find the local maximum of modularity, and a community aggregation to build a new network gathering all the nodes of each community in one node. This new network is used in the following modularity optimisation until the maximum of modularity is achieved. All this computation has to be made using multiple available software, Gephi (Bastian et al., 2009) being one of the most popular in the context of social networks due to its interactive interface and visualisations.

3 RESULTS

The selected works have been published between 2002 and 2019, 2018 being the most prolific year (14 articles). As the search for 2019 has only been conducted for the first nine months and therefore a reduced number of papers can be expected, we observe an increasing interest in the scientific community in the study of maritime transport seen as CN in the last decade.

3.1 General description of the data used

Having identified the relevant literature, it becomes interesting to describe the main characteristics regarding their data source, geographic scope or methodology analysis of the papers to better understand what type of resources are used in these researches.

Due to the difficulty for researchers, as mentioned above, to obtain reliable traffic data and maritime statistics in comparison with other modes of transport, it is relevant to know which are the original data and the sources of information. Twenty-eight of the articles use some of the tools made available by Lloyd's Register to its clients (Lloyd's Register, 2019), and CI-online is specifically mentioned by other five papers. Nowadays the group of tools and brands of this company is called Informa.

Other more geographically localised studies such as Wang et al. (2019) and Wang et al. (2018) claim to use data from “China Shipping Weekly” while Tsiotas & Polyzos (2018), Tsiotas (2017) and Tsiotas & Polyzos (2015) use data from the “Greek Maritime Network”. Other tools used as sources of information are Alphaliner (2019), UN Comtrade Database (United Nations, 2019) and other sources like questionnaires mailed to experts (Lekakou & Remoundos, 2015).

The Automatic Identification Systems (AIS) is a technology designed to automatically provide information about a ship to other ships and to the coastal authorities. Since 2005 (IMO, 2019), Regulation 19 of SOLAS requires AIS to be fitted aboard all passenger ships and most gross tonnage vessels.

Some articles complete their sources of information with data from corporate annual reports, websites, social media, firm documentation, archival records, and semi-structured interviews (Palmieri et al., 2019). Four of the papers (Woo et al., 2013; Tran & Haasis, 2015; Caschili & Meda, 2012; Delgado et al., 2018) used other published papers as sources of information as they have a bibliometric orientation.

Regarding the geographical scope of the papers, seventy-nine mention a specific geographical area, most of them (51) focusing worldwide. The decision of most studies not to focus on a narrow geographical scope gives an indication of the characteristics of maritime traffic in terms of globalisation, although there is no absence of examples of studies for local areas such as Osório et al. (2013). Asian countries have a special interest when analysing a specific region: seven papers deal with Asia in general, six focus only on China, and three others on the Maritime Silk Road.

From a methodological point of view, an interesting characteristic of these papers is what the nodes and links represent. Eighty-two of the selected articles mention specificities of the nodes and the corresponding links. As expected, the vast majority (57 of them) modeled seaports as the network nodes. In these cases there is a great variety of objects modelled as links, although all relate to the connections between these ports through ships with slight differences (see Table 2). For the other works modelling other types of objects as nodes, a summary of their characteristics is presented in Table 3.

-------------------------- TABLE 2---------------------------------------

---------------------------TABLE 3---------------------------------------

In relation to the main CNA measures usually considered by the analysed papers, those with more than one occurrence are shown in Figure 1.

----------------------FIGURE 1-----------------------

Sixty-nine of the papers specifically refer to a time period in their studies. The most frequent time domain (21 of them) is based on data obtained in a calendar year. Examples exist of a more extensive time window, for instance 1996-2006 (Ducruet & Zaidi, 2012; Ducruet et al., 2010b), or 2001-2012 (Xu et al., 2015), and very long-term datasets such as 1890–2010 (Ducruet, et al., 2018) or Tran & Haasis (2015) who studied the optimization of container lines between 1968 and 2012.

There are also other studies with a very small temporal scope such as Yu et al. (2017) with data from May 2014**.**

3.2 Article grouping

For a convenient analysis, the 97 selected articles could be split into two large groups according to their content and approach. Firstly, papers whose main objective is to perform a CNA of maritime traffic, usually focussed on describing the topology of the transport network using a clearly defined data set. Papers in the second group tend to use CNA in conjunction with other tools for the resolution of real problems related to maritime transport, that is, papers dealing with a specific topic related to the maritime traffic, with some reference to CNA methodology. Bearing in mind that some of the articles belong to more than one category, the distribution of papers is sumarised in Table 4.

----------------------Table 4----------------------------

3.2.1 Papers dealing with a topological description of maritime networks

The category with the highest number of articles, sixty-one in total, correspond to papers modeling global or local maritime traffic using a general approach based on CN. Starting with the empirical analysis of Wei-Bing, et al. (2009) which found that the structure of the Worldwide Marine Transportation Network is a small-world network exhibiting an exponential-like degree distribution. It possesses a relatively low efficiency compared to other transportation networks, and presents strong correlations among the container throughout, the degree and the clustering coefficient.

Among the global studies, Ducruet & Notteboom (2012) (as well as Ducruet [2017] for a long-term data set in the period 1977-2008) analyse the main world hub ports and the nodal regions, presenting a graphic description of the traffic in different time periods, thus being able to verify the temporal evolution of centrality in worldwide maritime traffic, and therefore the flows of international trade. Among their findings, they observed a significant increase in the centrality of the Asia-Pacific area and a certain robustness in the network structure.

In the papers in this group it is common to split the global shipping network into clusters or communities in order to analyse its structure (Pan et al., 2019), or its evolution. Xu et al. (2015) observed the period 2001 to 2012, highlighting an uneven evolution process of world regions in the global shipping network that has been proved to be spatially and structurally heterogeneous (Liu et al., 2018), and strongly constrained by the economic context of each region itself, which makes the global shipping network very volatile as was the economic environment itself. Other cases include networks having diverse types of links between nodes allowing the representation of commodity specialisation and nodal regions in a multigraph (Ducruet, 2013), or illustrating the liner shipping network as done by Cullinane & Wang

(2012) with the 18 major container ports in East Asia, or the flow movements (Wang & Cullinane, 2014) with hierarchical structures.

It is not common to compare the maritime transport network with other means of transport, so it is worth highlighting the effort of Woolley-Meza et al. (2011) using a set of data from 2007. They compared the global cargo-ship network with the worldwide air-transportation network revealing the similarity of both networks in terms of their measures of centrality. Also, Ducruet et al. (2011) analyzed air and maritime networks with a joint analysis of the two networks underlining their complementarities in shaping the global urban hierarchy. Finally Parshani et al. (2010) introduced two quantities for measuring the level of inter-similarity between networks namely the “inter degree-degree correlation” (IDDC) and the “inter-clustering coefficient” (ICC). They used simulation models analyzing the port-airport system.

Most of the papers do not take into account the intensity of the relationships among the nodes (unweigthed networks). For instance Ducruet & Zaidi (2012) use direct and indirect calls between ports to calculate key indicators of the situation of the ports in the network, verifying the existence of coherent subgroups of ports with crucial importance of the Europe–Asia link, with Singapore as a vital bridge. This and other papers such as Laxe et al. (2012) highlighting the importance of China, Ducruet et al. (2010b) focussing on the Atlantic trade, and Hu & Zhu (2009) with a global scope, confirm that the container shipping network is a scale-free structure with small-world properties. Within the family of small-world networks are also networks like the Cooperative Container Network, CCN (Caschili et al., 2014). However, other networks with a much smaller geographical scope such as the Greek Maritime transportation Network, GMN, was not identified as a small-world network because its binary diameter consists of 15 steps (Tsiotas, Polyzos, 2015).

Other papers look at the CN as a weighted netwok including in their analysis the traffic flows or other measures of the relationships intensity. Bartholdi et al. (2016) and Kaluza et al. (2010) conclude that if the network weights are taken into account, in the global cargo ship network the highly connected ports not only have many links but their links also have a higher than average weight; as for the container ship traffic, its network is more clustered.

Regarding the main measures studied in the networks, centrality is a fundamental concept to know the strategic role and influence of each port in the maritme system. It has been widely studied both globally (Wang & Cullinane, 2016; Montes et al., 2012) and in specific regions (Lu et al., 2018). On some occasions it has been studied along with connectivity, not only in ports but in world shipping areas (Li et al., 2015) or American countries (Calatayud et al., 2017). Centrality can also be used to evaluate port strength on the shipping network (Tran & Haasis, 2014) as well as its vulnerability as shown by Ducruet et al. (2010) in the case of the Northeast Asian Region.

It is worth noting the research efforts to describe the maritime network as a complex network over long periods of time (1890-2000), concluding that the diameter of the network remains constant over this period (Kosowska-Stamirowska, et al., 2016). The interdependencies between shipping flows and urban development was studied by Ducruet, et al. (2018) considering city hubs and the number of vessel calls in the years 1890, 1920, 1950, 1980 and 2010. It is also important to highlight the first-ever analysis of global maritime networks in relation to urban development (Ducruet, et al., 2016) which concluded that the influence of city sizes had a tendency to decrease during the period studied (1950-1990).

Finally, by using network theory it is possible to describe the relative importance of each port or region, and visually represent diverse concepts like foreland (Seoane et al., 2013); the possibilities for cooperation between liner shipping (Bergantino & Veenstra, 2002); cooperation between international terminal operators (Parola et al., 2014b); port competition in East Asia (Ducruet et al., 2011b); the quantification of potential for logistics hubs (Veenstra et al., 2005); decision-making on hub location in the Caribbean Region (Sun & Zheng, 2016); or the connectivity potential and competitiveness of the Canarian ports (Tovar et al., 2015).

It deserves mentioning the complete research of Arvis et al. (2018) that analised port centrality and vulnerability to competition, measured trade connectivity and connectivity patterns in the Mediterranean area. This research found interesting shipping patterns for the 2009–2016 period. Finally Fang et al. (2018) proposed an AIS-based approach to explore maritime networks, providing a tool to compare time-series variations driven by international events and identifying connected links with similar dynamics close in time to the events.

Results revealed the drastic decline of traffic between India and other countries as a result of military conflicts and the great rise of tanker shipping in Iran after the lifting of economic sanctions, among many other examples of this nature that proved the suitability of this approach to understand the dynamics of the maritime network dynamics.

3.2.2 Papers applying a CNA approach to specific topics

As mentioned, other articles do not deal precisely with a CNA of the maritime transportation, but they focus on a specific topic regarding this industry, and in one way or another they make use of CN to study the subject. Up to 30 different techniques and tools (in addition to the Complex Network approach itself) were used by these papers. Among the most recurrent we can mention Game Theory models, the use of metaheuristics, or location-routing models.

A grouping according to the topic covered follows.

a) Network design

The designing of the logistics network is a key issue to provide an efficient service, and therefore many studies have focussed on this problem. Examples include the network design of hub ports with the cooperation as a potential substitution for competition, researching the impact of competition/cooperation among the hub ports and shipping companies (Asgari et al., 2013). Other papers focus on issues related to the planning of operations and the management of the network of freight carriers (Crainic, 2016) or in developing a strategic network model based on equilibrium principles, analysing the international liner shipping network in various long-term scenarios and facilitating decision-making in response to endogenous and exogenous shocks (Lin & Huang, 2017).

There are also examples of the compilation of characteristics of the public transport network and its evolution (Majima et al., 2016), the generation of a hub & spoke network for public transportation (Majima et al., 2017), or the study of the linkage intensity between subnetworks (Yu et al., 2017).

Other papers in this group have considered the trajectories of the ships. Thun et al. (2017) analyse them, ranging from simple cycles seen by those visiting each port at most once in a service, to butterfly services, or even more general structures in which each port can be visited several times in a service. The topological characteristics of the network design was studied by Gastner & Ducruet (2014), Xu et al. (2016) and Hu & Zong (2013). Finally, Notteboom (2006) focussed on the port market environment and its impact on the performance of ports as logistics nodes in global networks and their design.

b) Risks and Vulnerability

The robustness of the logistics network is another important factor to consider when designing transportation structures, as its resilience makes it possible to continue with operations once any unplanned event has occurred. Six of the selected papers focus on the network vulnerability and six on the risks associated with the design and operation.

Regarding vulnerability, Ducruet (2016) calculated the global network structure and node centrality of the dataset of the vessel movements in 1996 and 2006, studying the role of canals and ports in liner shipping flows. A novel estimation of the importance of canal traffic in global container flows was provided and the higher vulnerability of the "Old Atlantic world" compared with the Asia-Pacific and South Atlantic regions was revealed.

Calatayud et al. (2017b) modelled 80 networks and simulated attacks on seven strategic nodes in America, studying their impact with measures such as "betweenness centrality". They concluded that there are different levels of vulnerability for maritime flows depending on the positions occupied by the countries in the network. Other works focussed on developing a framework with models to identify and analyse vulnerabilities in supply chains, taking as an example Maersk maritime lines in their Asia-Europe routes to demonstrate the applicability of the CN proposed framework (Liu et al., 2018). Given the power-law distribution of the degrees, they found that the Asia-Europe routes of Maersk are not homogeneous, with a few port hubs working most of the lines. The network studied presents robustness against random failures, but seems to be more vulnerable to deliberate attacks against highly connected nodes.

The robustness and flexibility of the maritime container network have been studied to check its adaptation to changes in service configuration from a complex network perspective, proving the high robustness of the network (Viljoen & Joubert, 2016). From a similar perspective, Wu et al. (2019) considered the vulnerability of the network formed by the routes of the 100 most important container line companies to comprehensively determine the impact of the interruption of the main channels (Malacca, Suez or Panama) on the vulnerability of the global container shipping network. Finally, Guo et al. (2017) focussed on analysing centrality, spatial structure and vulnerability of the domestic China-Japan-Korea shipping network, showing the presence of a pole-axial topological structure and a multi-hub axial radiation network, which could help to solve the contradiction between service concentration and hub congestion.

Other papers were more concerned about the risks involved. Ide et al. (2015) used AIS data with real-time location of vessels to perform a risk analysis of global maritime networks. Rokseth et al. (2018) focussed on the processes of verification systems in maritime transport, proposing a methodology aimed at improving the current verification and testing approach for maritime systems. Tang et al., (2010) and Angeloudis et al. (2013) studied the robustness and security of container marine transportation networks and related risks, while Achurra-Gonzalez et al. (2016) modelled the impact of perturbations in the container cargo routing. Finally, Bichou et al. (2013) used a framework of complex networks to identify points of failure in the network that can lead to its collapse.

c) Supply Chain Management (SCM)

Maritime activities are involved on many occasions in Supply Chain Management operations (Song & Lee, 2009), and therefore it is not strange that five of the selected papers have a relevant focus on SCM analysis. Gerschberger et al. (2012) present a model to determine complexity in supply networks. A more practical research based on complex networks discusses the practical implications of the small-world and scale-free characteristics of the studied supply chain networks (Liao et al., 2017). The remaining papers deal with understanding the network properties that underlie efficient supply chains (Hearnshaw &

Wilson, 2013), and two other papers (Bichou et al., 2013; Liu et al., 2018) were concerned about SCM risk and vulnerablity as commented above.

d) Other Networks

A group of eleven papers have no common topic when analysing the maritime traffic, but they discuss a variety of issues in this field. Here we include the use of Bayesian networks to model variables in the port system (John et al., 2016), or the modelisation of the carrier interactions in international maritime freight transportation networks (Lee et al., 2014). Other papers presented more diverse approaches such as an experiment on participatory planning of coastal shipping services in Greece (Lekakou & Remoundos, 2015), or the development of the Single Window concept for the multimodal door-to-door freight transport management (Osório et al., 2013), or the definition of a Network-based Integrated Choice Evaluation (NICE) model (Tang, et al., 2011).

The different topologies of transport systems have also been studied by means of complex networks, studying maritime transport in combination with other transport systems (Zanin et al., 2018). Within this category it is also possible to find examples of knowledge networks in the maritime economy (Bentlage et al., 2014) and articles with approaches as different as interactions among organisations in the same maritime cluster (Pinto & Cruz, 2012), the level of internationalisation of the container shipping companies (Gadhia et al., 2011), cities in transport networks (Ducruet & Lugo, 2013) or the network made up of 632 keywords from 133 papers regarding research trends in European ports around the Baltic Sea (Delgado et al., 2018).

3.3 A CNA of the keywords

Another approach to understand the nature of the research body in the field, as well as the main topics and methodological tools employed, is based on studying the list of keywords in the selected papers, and their relationships. These relationships among keywords can in turn be represented in a weighted undirected complex network in order to study its structure and its tendency to connect more with some keywords than with others. In this case, the nodes of the network represent the keywords, and two keywords are linked when there is at least one article that mentions both. The weight of each link defines in how many papers this pair of keywords appears.

Previously, non-adding information keywords such as “Maritime”, “Ports” or “Shipping” among others, and those which were used in the search of the selected papers (such as “Complex Network” and “Network Analysis”) that appear in all the manuscripts, have been removed for a cleaner analysis of the interaction among the keywords. The network is composed of 173 nodes and 376 links. Focusing on the giant component which excludes isolated keywords or small components, its 141 nodes and 348 links is represented in Figure 2.

--------------------------------FIGURE 2--------------------------------------

The average degree of the nodes is 4.16 and its weighted average degree is 4.50. The density of the network is 0.025 and the average clustering coefficient is 0.82 with 315 triangles, namely, triplets of keywords fully connected among them. Note that the average clustering coefficient is quite high when compared to a random network of the same size, its average clustering coefficient would be 0.035. That is, the keywords have a group of other keywords with which in general they are related and appear frequently.

----------------------- TABLE 5----------------------

By applying the algorithm of Blondel et al. (2008) for communities' identification, all the nodes get distributed among 10 communities to which we have assigned an overall topic that groups each of them (see Table 5), with different colours randomly assigned to each.

The Green Community (named “Port-city relationships”) is the largest in the giant component. It has 20 nodes and 33 edges and its keywords are related both to cities and flows as a system. In this community the main keywords are “Spatial networks” and “Port hierarchy”, which are significantly connected with the others in its group. For its part, the Light blue Community (“Structure”) involves keywords related to the connectivity of the network. We can find keywords like “Carrier Interactions”, “Port Choice”, “Alliances”, in addition to those in Table 5.

The Brown Community (“Regional Analysis”) gathers papers about maritime applications on different regions. There are keywords such as “clustering methods”, “spatial development” among others. On the other hand, the Orange Community (“Networks’ Topology”) groups multiple keywords about different metrics used in CNA to describe and categorise networks.

The topic of Magenta Community (“Resilience”) is related to the capacity of the network to allow business continuity, as its main keywords are “Risks”, “Resilience”, “Robustness” and “Sensitivity analysis”. In this community other topics such as “Verification”, “Port sustainability” and “Safety” are present. The Dark Green Community (“Main Flows”) is related to the structure of the network using Automatic Information Systems. Two of the main keywords of this community are “Flows” and “Hubs” which usually are mentioned together, and are linked with others of lower PageRank such as “Traffic consolidation”.

The Dark Blue Community (“Logistics”) collects case studies on Logistics and Supply Chain management. The Purple Community (“Research”) gathers keywords on efficiency and productivity. In this community we can find keywords such as “Data science” and “Research collaboration”. Alternatively, the Yellow Community (“Economic trends”) involves different applications about economics and Big Data. Finally, the Grey Community (“Investment planning”) is the smallest one with 7 nodes and 12 edges, whose papers are related to Investment research and topics like the Maritime Silk Road.

As mentioned above, the communities are composed of those nodes that have more connections among them than with the rest of the network. However, the communities may have stronger connections with some communities than with others. Figure 3 shows the connections among communities highlighting the nodes that have an important position in the intermediate geodesic paths of the network. In this figure, the size of the nodes is proportional to their value of betweenness centrality.

---------------------------------FIGURE 3---------------------------

As can be seen in Figure 3 nodes in the same community are strongly connected. The keywords “Transportation” and “Connectivity” connect the Light Blue Community (“Structure”) with the Magenta Community (“Resilience”) and Dark Blue Community (“Logistics”). Both Light Blue Community (“Structure”) and Purple Community (“Research”) also have relationships with the Yellow one (“Economic trends”). The latter also has multiple relationships with the Dark Green one (“Main Flows”) using the keyword “Flows” as a bridge.

The Purple Community (“Research”) is connected with a wide range of communities by the keyword “Centrality”, except with the Grey, Brown and Magenta (“Investment Planning”, “Regional analysis” and “Resilience” resp.) Magenta Community (“Resilience”) has multiple relationships with the Orange (“Networks’ topology”), while the Brown community (“Regional Analysis”) is connected with the Green (“Port-city relationships”) through the keywords “Clustering methods”, “Regional analysis”, “Spatial networks” and “Scale-free”. The Brown community (“Regional Analysis”) is also related to the Grey (“Investment Planning”) by the keyword “Regional Analysis”.

As can be observed, most of the connections among different communities appear through keywords with high betweenness being what makes communities logically connected among them. Moreover, the lack of relations among communities in that Figure indicates potential future areas of research to explore.

4 CONCLUSIONS

This paper reviews the complex network approach of maritime traffic research, based on 97 selected papers from the relevant literature. Most of the papers model maritime traffic as a CN where the nodes are ports and their edges are maritime lines between them. The selected papers have been divided into two main groups depending on the role of CNA in that research. All the papers have been reviewed individually and summarised, extracting the most important data from each of the categories. A general analysis of the papers have been performed synthesising their main characteristics, like CNA measures considered, sources of information, geographical scope, time period, and the role of nodes and links in the network model proposed.

The CN approach proves to be efficient to gain a better understanding of the structure and evolution of the maritime traffic, and to understand the commercial links that ports establish with each other. Using network modelling makes it possible to study the centrality of the maritime network by discovering its most connected nodes. It is a convenient tool as well to analyse different levels of vulnerability for international flows and therefore to identify risks such as labour strikes, trade embargoes or natural disasters, which may result in disruptions in the global supply chain performance.

Analysing the connectivity of the ports using CN makes it possible to graphically visualise concepts of great importance as the foreland of each port or region and to identify the most important hub ports and nodal regions in maritime traffic (Singapore, Hong Kong or Rotterdam in the case of container traffic). Possibilities for cooperation and establishing co-operative agreements with other actors can be explored more efficiently by having information available to exploit possible synergies or promote collaborative management as strategic responses to the increasingly competitive environment of maritime transport.

The CN approach provides academics and decision-makers with a global view that could allow the evaluation of inter-port relationships as a whole. Changes in the design of the global network, in the competitiveness of specific ports, or even economic fluctuations in world regions, may have a direct impact on the structure of the entire maritime transport port system and needs to be studied with a global approach such as that provided by CN. For instance, on the whole it was observed that shipping networks have some CN properties, including short average path length, power-law of degree distribution, as well small-world and scale-free properties, which allows assessment of the robustness observed in the global liner shipping network structure.

However, the lack of precise data on the relationship between ports and the traffic generated between them prevents a more extensive application of network theories to the global networks of maritime containers and maritime traffic in general. The positions of the ports in the network are influenced not only by the decisions of the maritime lines, but also by factors that are difficult to quantify, such as technological advances and local political decisions that can have a great impact on the performance of ports and other infrastructures involved in maritime traffic.

Although there are some interesting studies in the scientific literature that introduce factors that make it possible to create more elaborate multilevel graphs such as the geographical and economic ones, the aforementioned lack of reliable data may result in relevant data remaining hidden, and therefore the modelling of marine networks may not accurately reflect current situations, nor can they identify future trends in maritime traffic. It is worthy to remark that CN allows to find out many properties in the networks, but in return they need a huge amount of reliable data.

Regarding the relationship among the papers in the literature, a CNA has been carried out using their keywords as the nodes in the analysis. Ten communities were identified representing the main research interest topics. This grouping is quite in line with the main concepts analysed in the systematic review of the articles. As shown in Figure 4, the first group of papers commented in section 3.2.1 dealing with the topological description of some maritime networks is predominant in all the communities, except in the “Resilience” one, where the group of “Risk and Vulnerability” captures more manuscripts. The group of “Network design” is mainly associated with the communities “Network topology” and “Flows”, while the SCM group clearly contains keywords of the “Logistics” community. The remaining “Other networks” papers have their keywords spread over different communities.

------------------------ Figure 4-------------------

In addition to visually grouping the research topics most addressed by the authors of the selected papers, this model allows us to check the interactions among the various topics covered by papers that share keywords belonging to different communities. Two clear examples of this relationship among communities are keywords belonging to "Investment Planning" and "Regional Analysis", as well as keywords belonging to the communities "Port-city relationship" and "Regional Analysis.

It is not surprising to see that the most important keywords of the selected papers correspond to common concepts in CNA. In light of the results obtained and visually analysing the results of the analysis of the keywords, it can be concluded that this approach is particularly efficient for modeling maritime transport in a network, making easy to study its connectivity, centrality and vulnerability.

Research gaps and challenges observed after the analysis of the reviewed literature are summarised in Table 6 where these shortcomings have been classified into four categories. As some of them overlap, a double entry has been created to better group them. We observe that one of the most frequent limitations mentioned by the authors is the lack of reliable data or the difficulties in acquiring complete data series for the network modelling, as commented above.

------------------------ Table 6-------------------

The use of a longer time series is another weakness of most articles, although there are examples of reference research using very long-term data sets in the literature reviewed.

It would be highly recommended to use other variables that have not usually been used to complete the research studies analysed such as customs information, production of raw materials indices, evolution of the Gross Domestic Product of countries or regions and its influence on the maritime networks, and any other source of data that would allow the estimation of current and future consumption indicators will be helpful in some studies.

Although examples can be found of segmentation of traffic by their presentation (containerised, bulk, etc.) or for passenger traffic (cruises), no studies have been conducted that provide an analysis distinguishing the nature or type of goods in a given area.

The use of data sources that segment the nature of the products transported between ports would allow the creation of networks for each type of product in which the main characteristics could be studied with the techniques described in this paper.

This will allow, for instance, the creation of communities or the calculation of the most influential ports in these networks for each type of traffic (oil, automotive traffic, chemical materials) or those considered most important for the environment studied, thus allowing an understanding of the specificities of each traffic according to the nature of the goods transported.

If researchers could systematise these data and the above-mentioned variables, and cross-check them with traffic data, it would be possible to apply Business Intelligence and Deep

Learning techniques to improve the understanding of the factors that have influenced the development of maritime networks as we know them today, and above all to forecast future behaviours. This information would be invaluable to decision-makers who are involved in the design of maritime routes, the choice of ports for logistics activities or even political decisions for infrastructure investments in certain ports or the prioritisation of one port over another.

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TABLES & FIGURES

Tabla 1: Process of searching and refining of the selection of papers up to September 2019

Search items		“complex network”				"network analysis"	
		AND “maritime”	AND “container”	AND “shipping”	AND “maritime”	AND “container”	AND “shipping”
Papers retrieved	WoS	40	33	61	48	95	113
	Scopus	112	242	48	100	154	90
Papers Selected	WoS	29	20	30	10	10	15
	Scopus	37	16	35	23	17	24
Papers without duplicates		52	28	56	25	21	32
Papers after filtering		120					
Final papers available after snowballing		97					

Table 2: Links for the networks where seaports are the nodes in the CN

Links	Referencies	Number (Percentage)
Sea lines	(Ducruet et al., 2010b), (Lin & Huang, 2017), (Yu et al., 2017), (Bergantino & Veenstra, 2002), (Hu & Zhu, 2009), (Lekakou & Remoundos, 2015), (Tsiotas et al., 2018), (Cui, 2014), (Veenstra et al., 2005), (Lu et al., 2018), (Tovar et al., 2015), (Wang & Cullinane, 2014), (Ducruet et al., 2010), (Achurra-Gonzalez et al., 2016), (Xu et al., 2016), (Angeloudis et al., 2013), (Guo et al., 2017), (Jeon et al., 2019), (Hu & Zong, 2013)	19 (33%)
Routes	(Wang et al., 2018), (Wang et al., 2019), (Asgari et al., 2013), (Liu et al., 2018b), (Lee et al., 2018), (Wang & Cullinane, 2016), (Liu et al., 2018), (Lu et al., 2018b), (Song et al., 2019), (Kim & Lu, 2015), (Wei-Bing, et al., 2009)	11 (19%)
Ship passes, links, connections, trajectories, movements or flows	(Ducruet & Zaidi, 2012), (Ducruet, 2016), (Tsiotas & Polyzos, 2018), (Shibasaki et al., 2017), (Kaluza et al., 2010), (Ducruet, 2017), (Berli et al., 2018), , (Ducruet, 2013), (Ducruet & Notteboom, 2012), (Mou et al., 2018), (Viljoen & Joubert, 2016), (Tsiotas & Polyzos, 2015), (Tran & Haasis, 2014), (Sun & Zheng, 2016), (Pan et al., 2019), (Ducruet et al., 2011), (Ducruet, 2013b), (Gastner & Ducruet, 2014), (Wang et al., 2019b), (Kosowska-Stamirowska, et al., 2016), (Arvis, et al., 2018), (Fang, et al., 2018), (Woolley-Meza, et al., 2011)	23 (40%)
Shipping capacity	(Wu et al., 2019), (Hu, 2019)	2 (4%)
Hierarchy relationships	(John et al., 2016)	1 (2%)
Link-weight based on economics	(Bartholdi et al., 2016)	1 (2%)

Table 3: Nodes and links in the CNs of the papers analyzed, where nodes are not seaports

Nodes	Links	References	Number (Percentage)
Carriers and cooperative agreements	Cooperation between carriers	(Caschili et al., 2014), (Parola et al., 2014)	2 (8%)
Main lines	Shipping lines	(Tian et al., 2007)	3 (13%)
Firms	Exchange relationships and the underlying contract if present	(Palmieri et al., 2019)	
	Interactions with firms stakeholders	(Hearnshaw & Wilson, 2013)	
Countries	Import/export flows	(Calatayud et al., 2017); (Ansorena, 2018) ; (Wu et al., 2019); (Mesa-Arango, et al., 2019)	4 (17%)
World Regions	Inter-regional links with at least one connection	(Xu et al., 2015)	2 (8%)
	Significant flows	(Cullinane & Wang, 2012)	
Global Shipping Areas	routes	(Li et al., 2015)	1 (4%)
Actors in German maritime economy	Maritime services provided	(Bentlage et al., 2014)	1 (4%)
Papers (bibliometric analysis)	Author and institutional collaborations	(Woo et al., 2013)	1 (4%)
Ports, Port Sets, Geographical areas of Greece	Potential of maritime connections between prefectures	(Tsiotas, 2017)	1 (4%)
Origins, destinations and intermediate points for changes in types of services, modes or routes in Freight Transport System	Alternative routes between nodes	(Lee et al., 2014)	1 (4%)
Different call positions	AIS trajectories of vessels	(Seoane et al., 2013) ; (Laxe et al., 2012), (Peng et al., 2018)	4 (17%)
	Links between ports	(Montes et al., 2012)	
Key actors within the Algarve's maritime cluster	Knowledge and interaction	(Pinto & Cruz, 2012)	1 (4%)
Keywords	Relationship between the keywords	(Delgado et al., 2018)	1 (4%)
Terminal operators	They operate one terminal, at least, together	(Parola et al., 2014b)	1 (4%)
Cities	Vessel calls	(Ducruet, et al., 2016); (Ducruet, et al., 2018)	2 (8%)

Table 4: Article grouping

<table>
<tr><th colspan="2">Paper Type</th><th>Number of papers</th></tr>
<tr><td colspan="2">Papers dealing with a topological description of maritime networks</td><td>61</td></tr>
<tr><td rowspan="4">Papers applying a CNA approach to specific topics</td><td>Network Design</td><td>11</td></tr>
<tr><td>Risks and Vulnerability</td><td>12</td></tr>
<tr><td>Supply Chain</td><td>5</td></tr>
<tr><td>Other networks</td><td>11</td></tr>
<tr><td colspan="2">Unique selected papers (some in more than one category)</td><td>97</td></tr>
</table>

Table 5: Characterization of the ten identified communities of keywords

Communities	# nodes / links	Overall Topic	Main keywords (based on PageRank)					
Green	20 / 33	Port-city relationships	Spatial networks	Port hierarchy	Scale-free	Modularity	Urban development	System of cities
Light Blue	18 / 37	Structure	Transportation	Connectivity	Accessibility	Competitiveness	Multi-Level Hierarchical Game	Network Equilibrium Models
Brown	17 / 42	Regional Analysis	Regional analysis	Clustering methods	Maritime economy	AIS	Urban systems	Algarve
Orange	16 /37	Networks' Topology	Vulnerability	Suez Canal	Weighted network	Degree	Betweenness	Panama Canal
Magenta	15 / 27	Resilience	Resilience	Risks	Topology	Robustness	Review	Sensitivity analysis
Dark Green	14 / 25	Main Flows	Flows	Hubs	Linkage	Spatial isolation	Network dynamic structure	Concentration index
Dark Blue	13 /27	Logistics	Logistics	Supply chain	International Trade	Austria	Agriculture	Channel relationship
Purple	11 / 17	Research	Centrality	Throughput	Data Science	Seaport research	Research collaboration	Productivity
Yellow	10 / 15	Economic trends	Cities	China-Japan-Korea	Economics	Big data	Belt and Road Initiative	Intermodalism
Grey	7 / 12	Investment planning	Maritime Silk Road	Terminal investment	Investment direction	Terminal operators	Port competition	Herfindahl-Hirschman index

Table 6: Areas for improvement in maritime traffic studies with a focus on complex networks

	Technological	Strategical	Methodological	Data
Technological	*More extensive use of AIS and other data sources can be helpful. *Many researches are still in a theoretical stage *Difficult to measure certain factors by simple indicators.			
Strategical		*Take into account the time proximities between ports. *Distinguish between the types of port calls. *Deeper comparison is needed among connected ports in terms of performance indicators.	*Take into account policy and regulatory actions, and consider decisions of shippers and pubic bodies.	*Decompose the network into more layers (f.i., crude oil, refined oil products, and liquefied gas for liquid bulks, cruise, ferries, and roll-on/roll-off for passengers) *Add information about factors that can influence research (f.i., changes in global economies, social issues that may affect the product demands, or disruptive technological changes affecting the design of the shipping network)
Methodological			*Compare results with different network topologies (direct and indirect linkages among ports, or different representation approaches such as L-space and P-space) *Compare results from different means of transport *Check the interactions between economy evolution in different regions and the maritime routes. *Empirically check the theoretically obtained outcomes and findings. *Qualitative methods in the context of the maritime industry are required to triangulate the findings. *Networks are global and therefore the nodes in the clusters formed may be from distant regions, what can affect usefulness.	*Extend databases to cover all the currently existing liner routes. *Obtaining reliable or complete baseline data is a must in CNA. *Include data such as traffic directions or service level in the design of networks. *Most papers use a data set with a relatively small time series, and these time periods should be extended to eliminate seasonal effects. *Extend the study to other commodity types (containers, passengers, general cargo, liquid bulk,…)
Data				*Include weight of links and refine the analysis by carrier, vessel size, or service type.

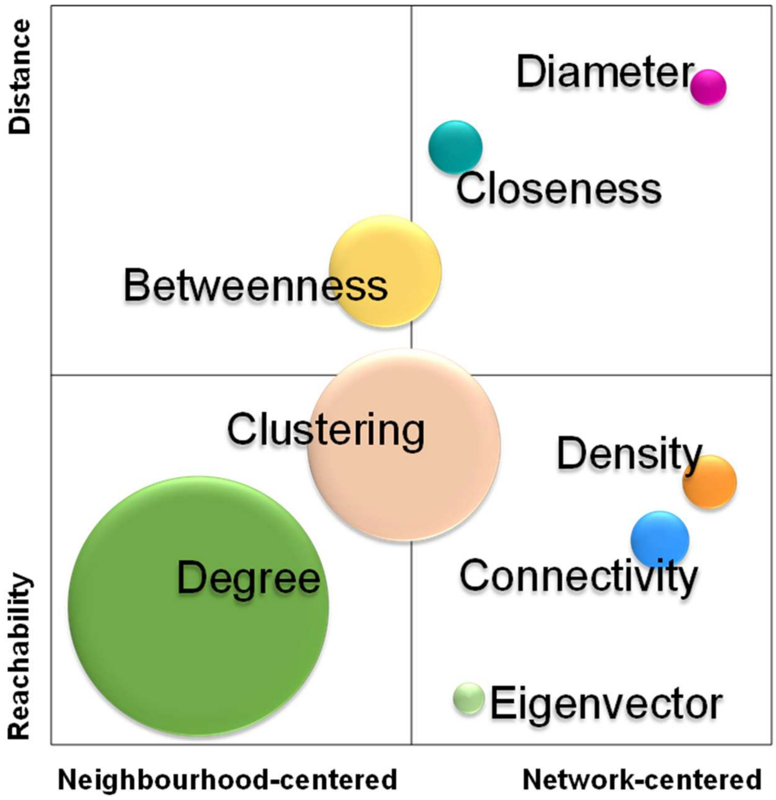

Figure 1: Main CNA measures used in the selected papers (bubble size proportional to the number of papers). Measures divided according to its focus on the use of distance or not, and its focus on the whole network or just node's neighbors.

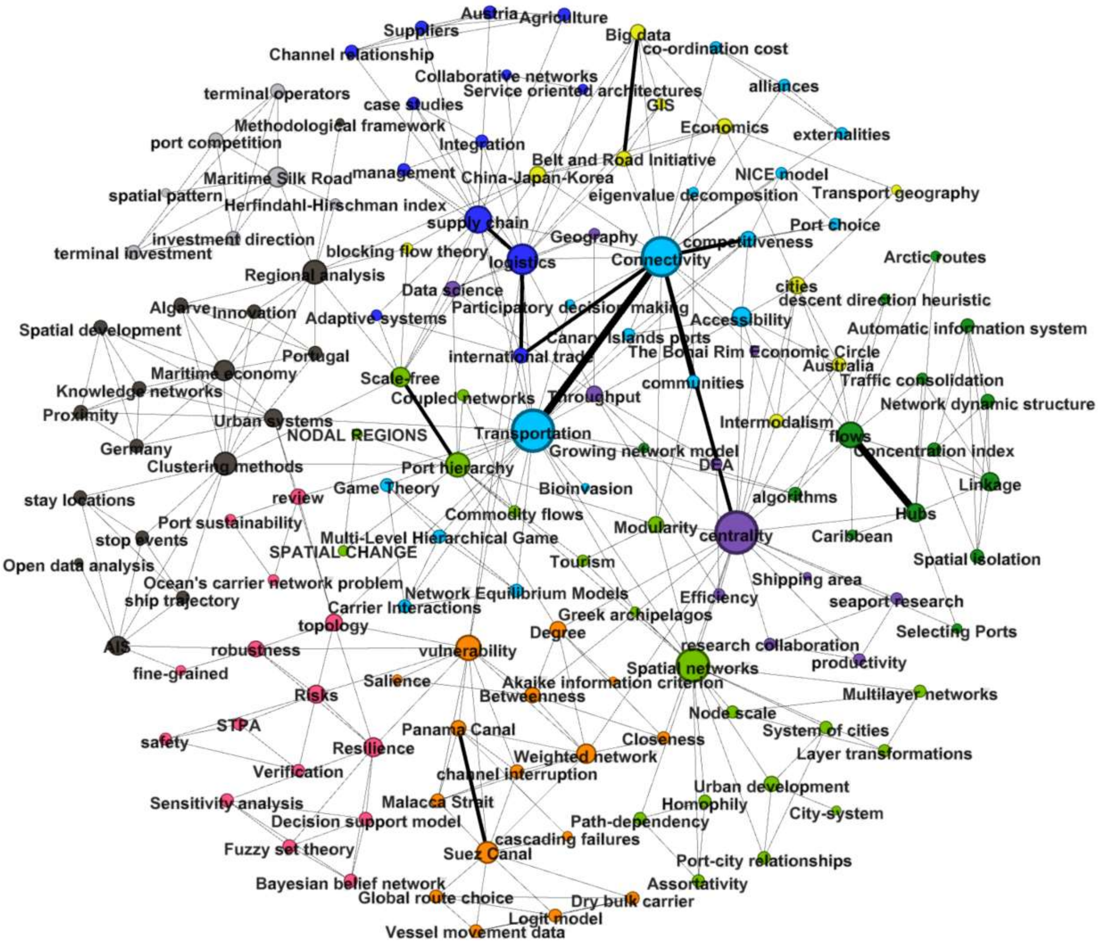

Figure 2: Giant component of the bibliometric complex network without the keywords "Complex Network" and "Network Analysis"

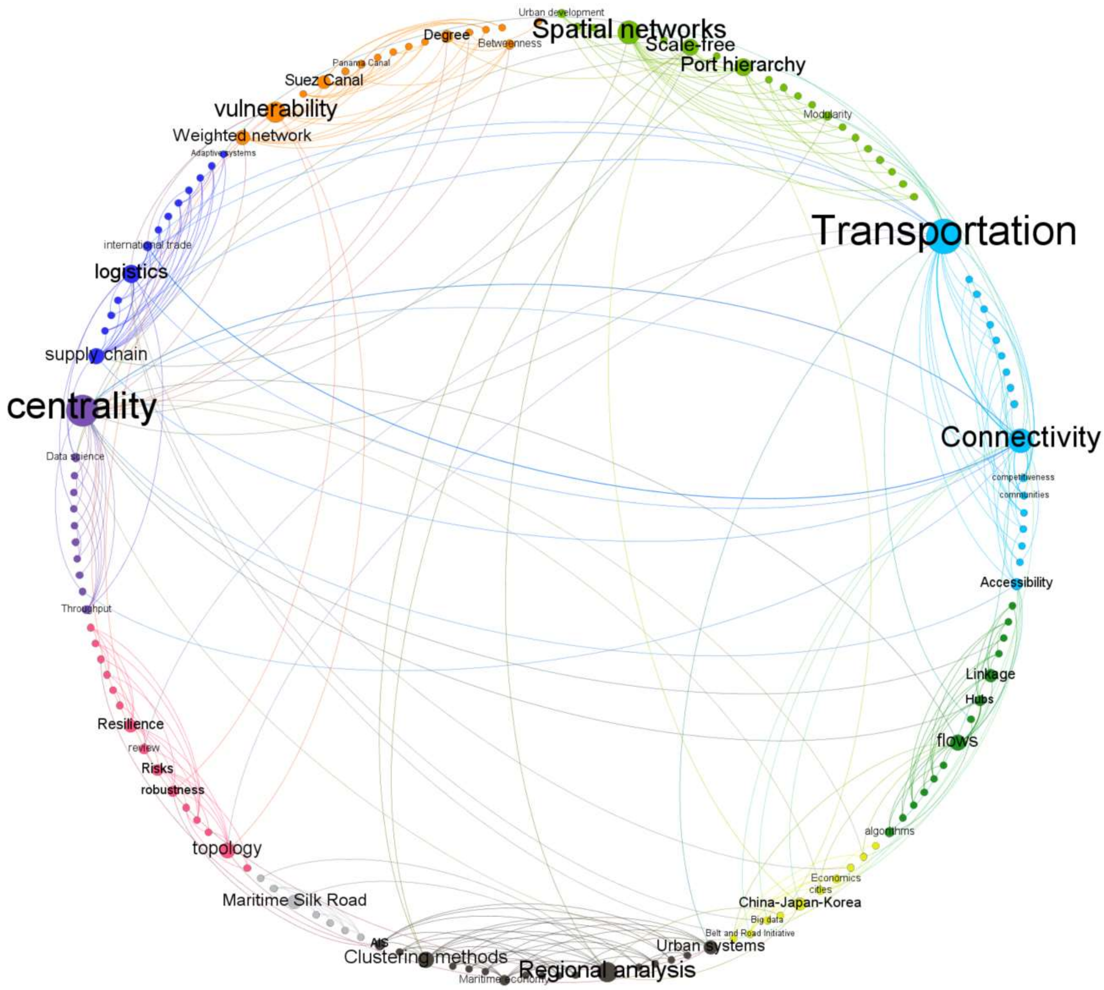

Figure 3: Giant component in a circle distribution, where the most important keywords according to their betweenness centrality are highlighted.

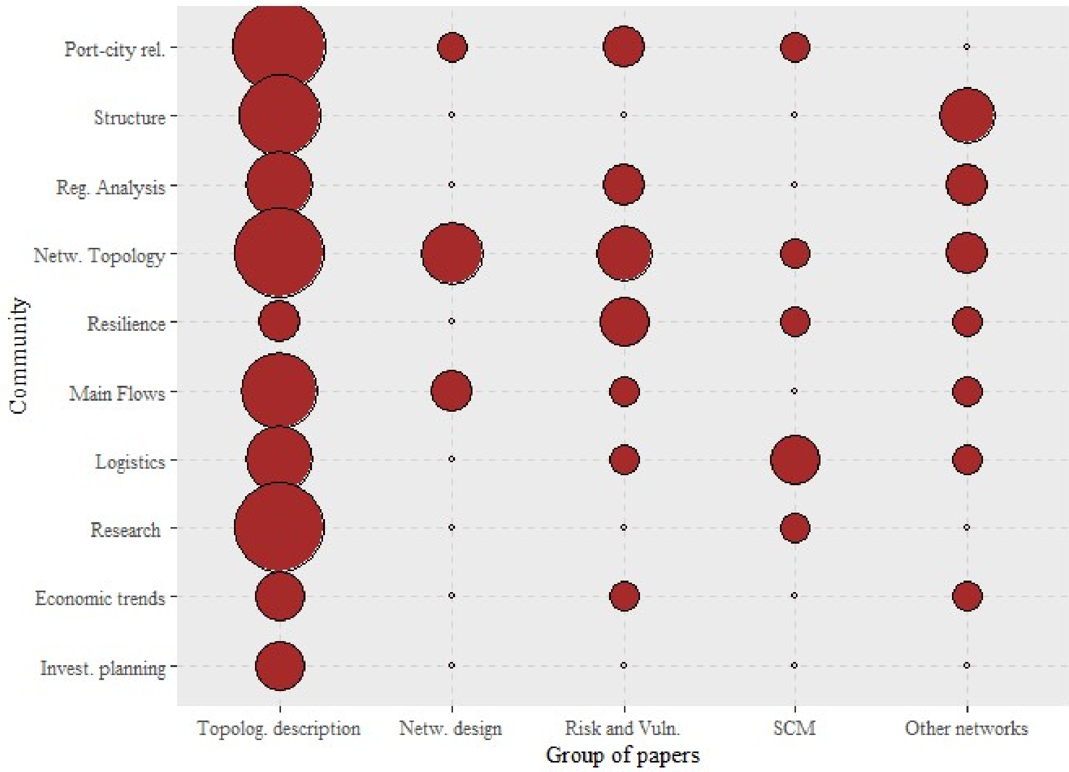

Figure 4: Number of papers of each group with keywords in each community.