The Importance of the Centrality of Ports for Passenger Transport in the Adriatic-Ionian Basin

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Abstract. The European port system must continue to play a strategic role considering three different aspects: economic, geopolitical and logistical.

Several parameters can be considered in order to improve the definition of these transport nodes and among these the study of centrality is of fundamental importance. This study focuses on the analysis of the network of passenger transport services within the Adriatic-Ionian basin that are part of the TEN-T network. To these ports (both core and comprehensive) was added Durres, which has the characteristics of a major port in the Adriatic basin, as well as being the main port in the Southern Adriatic, although not belonging to the EU context. The study was conducted by monitoring the systemic passenger transhipment services and initially evaluating the Origin-Destination matrix and for each pair of values the average weekly number of connecting services in the year 2023, extrapolating some considerations in the most critical months.

Through the calculation of the centrality parameters (Ci degree and Si force centrality), a partial correlation with seasonality emerged.

Specifically for 2023, it emerged that the value of Ci defines Igoumenitsa as the most central port in the basin for all months considered. The Croatian and Albanian ports are less significant on a basin scale.

Furthermore, the assessment of Si places Igoumenitsa, Bari and Ancona as the ports with the most connections. In the Croatian ports, a more marked seasonality emerges. In particular, it emerges that Croatian ports are more interested in tourism, which could mean that the Italy-Greece and Italy-Albania connections are also connections made for reasons unrelated to summer tourism.

These results lay the foundations for actions and strategies to improve maritime transport services and optimise passenger services at certain times of the year.

Keywords: Ports networks · Sea passenger transports · Degree and strength centrality · Sustainable mobility

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1 Introduction

Sustainable Development Goals are the main topic that guide the development of countries in terms of sustainability. The main document, "Transforming our world: the 2030 Agenda for Sustainable Development" [1] contains the main elements to be followed to pursue a sustainable development. Even if all the topics are of public interest, in this context it is useful to recall two specific goals: "Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" and "Goal 13. Take urgent action to combat climate change and its impacts". In a context of improve quality of life for people, reduce pollution and carbon footprint and reduce inequalities between people, a great attention has to be paid to modal shift towards more sustainable transportation means. Considering the environmental impact of several transportation mode [2] it is important to consider the importance of sea passenger transport [3].

In the context of European union, White paper 2011 on transportation [4] has severely recalled the importance of sustainable transportation and of an integrated space. Several maritime basins are included in the EU geographical area; most of them links different countries. So, sea transportation is also an opportunity to enforce links between European countries, in the context of the Trans-European Network on Transportation (TEN-T) [5]. Several European corridors consider ports as main node, and several ports are included in the Core network. TEN-T is meant to improve connections between European countries, with the possibility, for non-EU countries in the area, to cooperate. In this context, a primary role may be assumed by Adriatic Sea. Adriatic Sea is an open basin that links seven different EU and non-EU countries; Adriatic is linked to another basin, Ionian Sea, that separate Southern Italy from Greece. Adriatic Sea and Ionian Seas, together, form the sea that separate two of the three main southern European peninsulas: Italian peninsula and Balkan peninsula. The region considered is crossed by several trans-European corridors: Scandinavian-Mediterranean, in eastern Italy; Mediterranean, in north-eastern Italy and western Balkan; Baltic Sea-Adriatic Sea in Adriatic coast of Italy; Western Balkans, in Greece, Croatia and Slovenia. The latter one, also, includes several non-EU countries.

The importance of maritime transportation, and the key role of Adriatic-Ionian area in European development has been recalled. The aim of this work is to better understand the opportunities given by these basins in terms of passenger transportation. The topic is the study of centrality in network of services in the area, highlighting gaps and evaluating if there are point of strength and weaknesses.

Section 2 of this work discusses the evolution of ports and the role of passenger ports today. Section 3 shows the methodology used. For this analysis, tools from network analysis are considered, evidencing several indicators that can show different aspects of centrality in a network. Section 4 illustrates the results of methodology applied to the case study. Finally, in Sect. 5 results are discussed, and the most relevant conclusions are provided.

2 Ports Evolution

The United Nations Conference on Trade and Development (UNCTAD) classifies ports in four categories, starting from their functions [6, 7]:

- First generation ports are those directly connected to the city; the port is born even before the city itself. Genova, Trieste, and Venice are example of first generation ports;
- Second generation ports are large industrial agglomeration, often placed where they need to serve large industrial area. Taranto is an example of second generation port;
- Third generation ports are specialized in containers management and transportation. Gioia Tauro in as example of third generation port;
- Fourth generation ports are linked to the possibility to create multiple port-cities aggregation under the same authority. The creation of Port System Authority in Italy defines the desire to pursue fourth generation port models.

The availability of computing resources, 5G networks and clouds makes it possible to deliver port services in a way that can be as 'standard' as possible. In this sense, the pursuit of the re-appropriation of data allows the port system to configure itself as a fifth generation "Digital Hub". Therefore, the "new" port is no longer just a system that provides a portal of services, like a first-generation system, but is able to offer the possibility of accessing data to build a series of services, capitalizing on its use and versatility [8, 9].

Consider how the definition of generation k port does not imply an improved condition to a generation k-1 port; the idea of port generation is connected to the main functions performed by it.

It is important to establish the role of first-generation ports in the context of passenger transport. Second- and third-generation ports, serving industrial and commercial ports, are less concerned with passenger transport; fourth-generation ports, by definition, can fulfil several functions. First-generation ports have traditionally been those most concerned with passenger transport.

In particular, in open sea basins, the role of first-generation ports has been to be hubs for the exchange of people, as well as goods, between different countries. Several works in the literature refer to the connectivity and accessibility of sea-side ports, with reference to both port-city, peripheries and inner harbors interaction [10–13].

The effects of poor port connectivity have been studied by [14] emphasizing the limitation of competition between carriers, high freight rates and higher inventory costs for shippers, i.e. the main factors that jeopardize a port's international competitiveness.

Good connectivity is crucial for port and neighboring areas' growth.

As defined by [15] there is a relationship between connectivity-centrality taking into account the degree of difficulty of a port to connect to other ports in a global context.

The present research work is within the framework of the analysis of sea-side port connectivity, considering a basin-wide service system. In this sense, it is intended to recall how the tools that will be discussed in Sect. 3, network analysis, are used in the literature to describe seashore port connectivity problems but are also widespread for other transport systems [16–19]. The present work intends to develop an example of a study of port connectivity and centrality in an open basin.

3 Methodology

The methodology under consideration is described in Fig. 1.

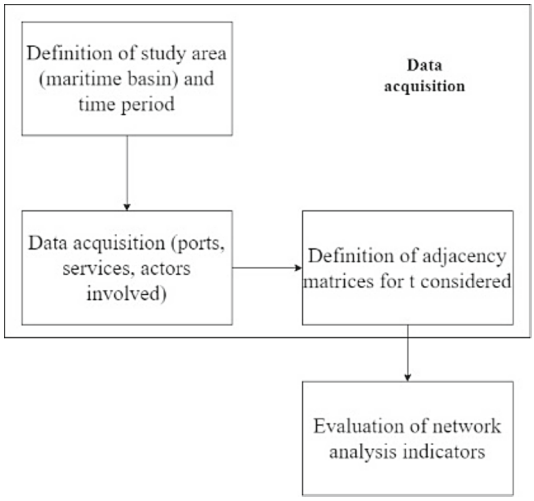

Fig. 1. Methodological framework

3.1 Data Collection

The elements to be defined for the construction of the network are:

- A maritime sea basin of reference;
- A time interval *t*;
- A criterion the identification of ports network. Ports are the nodes of the network;
- A quantitative parameter for the definition of a link

The central element of the analysis is the existence of one or more services connecting two ports. Once the reference basin is defined, *i, j* are defined as the generic pair of nodes. It is possible to define the ordered set $p_t = [i,\ldots,j]$ as the generic route *p* having origin in *i* and destination in *j* at time *t*, in which *i* and *j* are ports belonging to the identified basin. Since it is possible that the generic nodes *i, j* are not, respectively, the origin and destination of a route, it is necessary to generalize by introducing the nodes *z* and *s*. The generic route is defined as $p_t = [s,\ldots,i,\ldots,j,\ldots,z]$ as the generic route that includes a direct connection between *i* and *j*. Consider, in particular, how *s* and *z* do not need to belong to the reference basin; however, the existence of a connection between i and j makes their consideration essential.

Consider the existence of a route $p_t = [i,g,j]$, an ordered set that involves stopping at an intermediate node. The service considered, expressed by the route p_t, connects *i* to *g* and *g* to *j*. However, despite the existence of an intermediate stop, the service also connects *i* to *j*. To highlight this element, it is necessary to break down each route $p_t = [s,\ldots,i,\ldots,j,\ldots z]$ into the individual pairs of relations that compose it.

It is possible to define $k_t(i,j) = 1,2,\ldots,Kt(i,j)$ the generic connection between nodes *i* and *j* at time *t* on the network considered, being $K_t(i,j)$ also the total number of services between *i* and *j* at time *t*. In this way, it is possible to define also the adjacency matrix

of the network as

$$A_{ij}(t) = [a_{ij}(t)] \tag{1}$$

where

$$a_{ij}(t) = \begin{cases} 1, \exists k_t(i,j) \vee k_t(j,i) \neq 0, i/j \\ 0, \nexists k_t(i,j) \vee k_t(j,i) \neq 0, i/j \end{cases} \tag{2}$$

It is possible to define the adjacency matrix, therefore, starting from the condition of existence of at least one link connecting i and j regardless of the order in which they are considered. The service graph $G = (N, E)$ is defined, where $N = \{1,2,3,\ldots,i,j,\ldots,N\}$, $E = \{(i,j)|i,j \in N, i \neq j\}$.

3.2 Data Preparation

Network analysis allows the study of the characteristics of the network. The elements are the main indicators of the centrality of a network. Since each indicator is defined starting from different quantitative elements, it is essential to define different indicators. The purpose of this operation is linked to the need to show different aspects related to the centrality of networks. The first indicator considered is the Degree centrality c_i. It is defined as

$$c_i(t) = \frac{\sum_i a_{ij}(t)}{N-1} \tag{3}$$

where the variables have known meaning.

The degree centrality refers to the maximum centrality obtainable from a node. It is evaluated starting from the sum of the rows on the adjacency matrix and is related to the maximum number of connections that a node i could have $(N-1)$. This indicator, therefore, measures the centrality of a node by considering only the existence of connections with other nodes. In the specific case, considering the data proposed in Sect. 3.1, the degree centrality quantifies the number of ports with which the port in question is connected, at time t. A value of $c_i(t) = 1$ indicates that the port, at time t, has at least one connection to every other port in the network. The degree centrality indicates the possibilities offered by the system, but sometimes it is necessary to introduce a further quantitative term, associated with the arc, to further define the centrality of the network. Consider a case where node i is connected to node j and node z at time t. However, in the example considered, it should be noted that node i has three connections with node j, and only one with node z. The Degree centrality, in this case, returns the same value to both connections: it gives topological information on the network.

To partially solve this problem, it is possible to introduce a quantitative measure associated with the generic edge (i,j). In the case in the measure proposed is the number of services that connect i and j at time t. The indicated term, $w_{ij}(t)$, is defined as

$$w_{ij}(t) = K_t(i,j) + K_t(j,i) \tag{4}$$

It is possible to define the second indicator, strength centrality, as

$$s_i(t) = \sum_j a_{ij}(t) w_{ij}(t) \tag{5}$$

The indicator quantifies for each node i the number of services with the nodes j with which it is connected. In this way, the resulting value can define characteristics in terms of the frequency of connections in the interval t, as well as the nodes j with which i is connected. The two indicators considered show complementary information. Finally, the application to the port system can be carried out by considering different periods t on the same network, verifying the existence of modifications. The possibility of existence of predominantly tourist destinations determines the need to consider seasonality in the system, and to evaluate the centrality as it changes.

4 Results

The study is focused on the network analysis of the service routes between TEN-T ports on Adriatic-Ionian basin.

4.1 Study Area

The case study considered is the Adriatic-Ionian basin. As mentioned in Sect. 2, it is an open basin, in which the western coast is entirely Italian, while the eastern coast is divided between six states: Slovenia, Croatia, Bosnia, Montenegro, Albania and Greece. Of these, Greece is the only country on the eastern shore of the Ionian coast. The five Adriatic countries have a very different coastline in terms of extension; Croatia and Albania are predominant; Montenegro and Slovenia have a smaller extension; the Bosnian coastal strip has a small extension. The ports chosen are those that:

- Belong to the TEN-T, Core or Comprehensive network, or its extension to neighboring countries;
- Are totally or partially passenger ports, and are included in at least one national or international passenger service route;
- Have at least one link with another port of the network.

The first of the two criteria considered allows the scope of application to be narrowed, limiting the study to a basin level, and therefore removing local connections; connections with smaller islands, for example, are often linked to specific constraints due to territorial continuity. Furthermore, the extension to neighboring countries extend the study to important realities at the basin level but outside of EU planning.

The second of the two criteria allows the study to be limited to ports that have an interest in passenger traffic with systematic characteristics. Finally, third criteria the third criterion allows to create a network that is entirely connected in at least one month of the year. Within the basin considered, and once the criteria for choosing services have been identified, the operators who manage sea transport services are defined in Table 1.

The network evaluation carried out identifies $N = 11$ ports. The ports are identified in Fig. 2.

Table 1. Operators considered in Adriatic-Ionian basin

Operator	Reference
TP Line	[20]
Krilo kapetan Luka	[21]
Liberty Lines	[22]
SNAV	[23]
Gomo viaggi	[24]
Jadrolinija	[25]
Venezia Lines	[26]
Adria Ferries	[27]

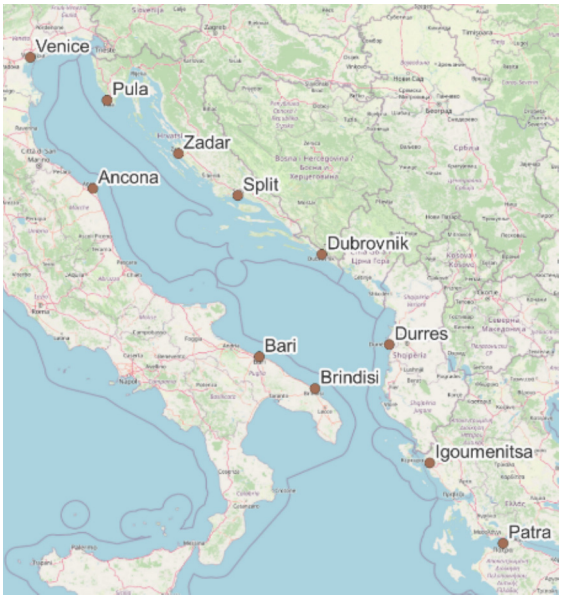

Fig. 2. Port network considered (Source: authors' elaboration based on QGIS [28] and OpenStreetMap [29])

Table 2 shows the main characteristics of the ports considering country and Core/Comprehensive network.

The ports considered are part of 4 countries of the 7 considered. The ports are all in EU countries, except for the port of Durres, indicated as a port of the Comprehensive network extended to neighboring countries. Once the basin, the operators, the services, and the nodes of the network have been identified, it is possible to define the number of services that connect nodes i and j for each t. Consider how the services identified present a considerable seasonality, with notable variations between months and minor fluctuations between weeks of the same month.

Table 2. Ports considered and their geographic characteristics

Port	Country	Core/Comprehensive
Ancona	Italy	Core
Bari	Italy	Core
Brindisi	Italy	Comprehensive
Dubrovnik	Croatia	Comprehensive
Durres	Albania	Comprehensive
Igoumenitsa	Greece	Core
Patra	Greece	Core
Pula	Croatia	Comprehensive
Split	Croatia	Comprehensive
Venice	Italy	Core
Zadar	Croatia	Comprehensive

Therefore, the reference time unit is the week of the month, and the value of services studied is the average number of services per week of the month. In this way, it is possible to reconstruct the average number of weekly services that, for each month, connect nodes *i* and *j*. This value is shown in Fig. 3.

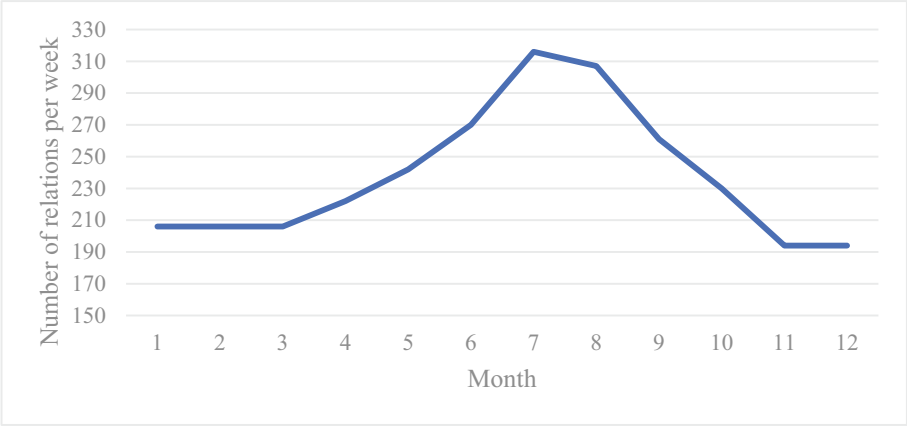

Fig. 3. Trend in the number of weekly reports over the different months.

In this way, it emerges that there is a rather marked seasonality, with a considerable peak in the month of July and high values also in the months of June, August, and September. This allows us to define the need to study the characteristics of the network in several periods, to evaluate whether there are any changes in centrality.

4.2 Network Analysis Indicators

Two months are proposed for the next results exposition: $t = 7$ (July) and $t = 11$ (November). They are, respectively, the month with the highest and lowest average number of services per week. Below is the representation of the network for $t = 11$ and for $t = 7$. Consider how the structure of the graph changes considerably between the two periods (Figs. 4 and 5).

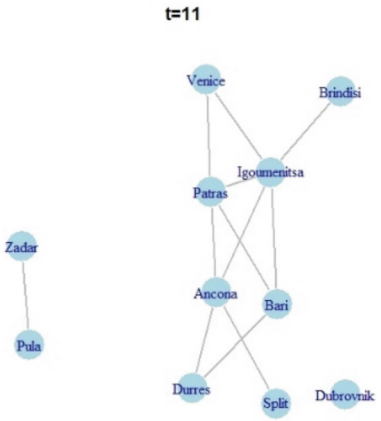

Fig. 4. Network considered, $t = 11$ (Source: authors' elaboration using R software [30])

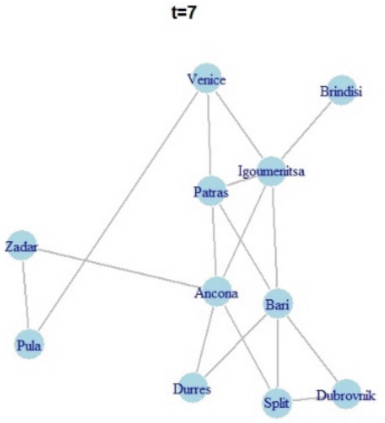

Fig. 5. Network considered, $t = 7$ (Source: authors' elaboration using R software [30])

Similarly, the summary of the results for the three indicators c_i and s_i for each of the nodes i of the network for $t = 7$ and $t = 11$ is proposed in Table 3. A considerable difference emerges between the values between the months considered, for both indicators. Although some nodes emerge with greater centrality (Igoumenitsa, Patras, Ancona), none of these have values greater than $c_i = 0{,}5$; this indicates that the network is not

very interconnected and there are no nodes of main importance at the basin level. The network is instead characterized by many one-to-one connections. Considering values of s_i, related to number of services per week, it is interesting to consider how several nodes see a strong reduction in number of services (especially the Croatian ones), while other see only a relatively small variation (Brindisi, Durres).

Table 3. Ports considered and relative Network Analysis Indicators

Port	c_i		s_i	
	$t = 7$	$t = 11$	$t = 7$	$t = 11$
Ancona	0,5	0,4	84	46
Bari	0,5	0,3	98	78
Brindisi	0,1	0,1	28	22
Dubrovnik	0,2	0	46	0
Durres	0,2	0,2	64	56
Igoumenitsa	0,5	0,5	132	98
Patras	0,4	0,4	70	64
Pula	0,2	0,1	20	4
Split	0,3	0,1	60	4
Venezia	0,3	0,2	18	12
Zadar	0,2	0,1	12	4

5 Discussion and Conclusion

Different considerations are necessary. The system considered has a strong seasonality; this is connected to the nature of some locations in the area considered, characterized by considerable tourist flows, especially in the summer season. Furthermore, only some of these locations are continuously connected to the rest of the system in any month.

The network had considerable variations between the two months analyzed. In the month of July, the formal representation of the port system considered returns a connected graph; in November, some nodes are disconnected from the system. Specifically, Dubrovnik has no connections with other nodes of the network, while Split and Zadar form an autonomous system. Consider how the three ports indicated are Croatian; they are involved mainly in passenger transport connecting main coastal citiese with the numerous smaller islands of Croatia. The port with the largest values of s_i and c_i is Igoumenitsa, Greece's gateway to the Ionian Sea and the main connection hub with other mediterranean countries. Igoumenitsa shows connections with the four Italian ports considered and with the port of Patra, in the northern Peloponnese, which shows considerable values of both c_i and s_i. Relative to Italian ports, the most significant values are associated with Ancona and Bari. The two nodes share the same connections in

the month of July (the two Greek ports, Split, and Durres), but have connections with Zadar and Dubrovnik respectively. Even the evaluations on eigenvector centrality tend to reward Igoumenitsa, Patras, Ancona, and Bari. It is appropriate to recall the absence of Italy-Italy connections in this context; vice versa, there are Greece-Greece connections. Services connecting Igoumenitsa to Patras are very widespread, often including several Ionian islands (mainly Corfu) in their routes. Similarly, there are several Croatia-Croatia services, also serving the smaller islands. The results generally show that:

- The centrality of Greek ports shows high values. This is probably linked both to the geographical proximity to various Italian ports, and to the presence of various tourist-oriented destinations in western Greece; this may also be related to the Greek geographical conformation and the lack of "direct" territorial continuity between Epirus and Peloponnese;
- The centrality values of Italian ports reflect, however, a less interconnected reality. There are no connections between Italian ports; this is probably linked to the greater competitiveness of the other modes on the Adriatic coast, entirely connected by high-speed rail services. An opposite situation occurs to that of the Tyrrhenian Sea, where there is a dense network of services that connects the main ports, thanks to the presence of two large islands [31];
- The low centrality values of Croatian ports instead reflect an even less dense situation. Croatia has coastal development and numerous smaller islands; there are several ports of global and local importance, but many of them are mainly linked to the service of the smaller islands;
- Finally, the importance of the port of Durres in the maritime connections between Italy and Albania is underlined. Although the port is relatively little central at a system level, it assumes considerable importance in the relations between the two countries indicated.

The services at the core and comprehensive network level in the Adriatic were studied. The focus was on the passenger and Ro-pax transport service, aimed at identifying the most central nodes and being able to define the weight characteristics of each node. The research has shown how in the Adriatic Sea, an open basin, different sub-systems interact between each other: in some of them, elements that refer to both transport on long routes and short trips are present at the same time. However, it was clear that the network is alive and vibrant and must be considered as a crucial element in a logic of decarbonization of transportation, supporting a modal shift towards the maritime in relations between the countries overlooking the Adriatic. Furthermore, it is intended to underline how the work carried out supports the logic of integration within the Corridors of the TEN-T network.

The research limited the analysis of services involving Core, Comprehensive or Extension ports, interested by passenger transportation services. This limit is linked to the desire to provide a preliminary analysis at basin level of the entire system; future developments may include a centrality analysis that also considers sub-systems, such as the Ionian islands and the smaller Croatian islands. Croatia has several archipelagos that form sub-systems whose centrality and connectivity certainly need to be investigated.

Another line of research concerns the possibility of quantitatively combining the results of port connectivity and centrality with those referring to other modes of transport.

As stated previously, the Adriatic coast is not connected by maritime services, but is equipped with a widespread HSR network; similarly, services seem to connect more with ports where there is no solid modal alternative, as in the case of Greek ports. This hypothesis should be tested by verifying whether port connectivity is complementary, or alternative, to rail connectivity.

Furthermore, the possibility of developing connectivity work for maritime services that considers the entire transport of goods on the same basin is highlighted; as mentioned in Sect. 2, the Balkan peninsula could become a reference point for the international transport of goods passing through the Suez Canal.

The research carried out is of interest to three categories of stakeholders: researchers, shipping companies and public administrators. The scientific interest of this work has been recalled in several passages; shipping companies can define, starting from the results, elements to improve investments in connections; finally, public administrators can start from the node centrality results to improve port-city interactions (such as improved transport infrastructure and services such as complementary services like demand responsive transport (DRT) or increased deployment of mobility as a service (MaaS) and relative digital platforms digital platforms)) and to push for sustainable solutions for both users and companies.

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