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# Maritime passenger transport in the Ligurian-Tyrrhenian basin of Italy: some considerations regarding their centrality

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**Abstract**

The problem of passenger transport in a geographic area, such as Italy, characterized by numerous port basins, must be adequately addressed to enable sea travel, accessibility to smaller islands also considering an increase in traffic. The key aspects for the development of maritime passenger traffic are the centrality of ports, as well as adequate infrastructure connections and maritime services. In order to enhance passenger flows to/from ports, it is therefore necessary to assess the relevance of ports to a basin of reference. A preliminary quantitative assessment of the maritime interconnections of ports at the transport network level highlights the presence of possible gaps. This paper aims to estimate the maritime centrality of ports with a methodology that considers the following three indicators: degree centrality (which considers the number of active sea-side) and two indicators of strength centrality (referring to frequencies and distances). The evaluation is made considering the network of passenger services and the number of services on a weekly basis. The methodology was applied to Italian and French ports located in the northern and southern Ligurian-Tyrrhenian basin, using data and information provided by port authorities and shipping companies. This work can lay the foundation for a more in-depth analysis of the strategies that port authorities and companies operating maritime-port services should adopt to increase passenger volumes in the coming years.


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*Keywords:* Port centrality analysis, Passenger maritime transport, Italian ports, Maritime services, Development strategy

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## 1. Introduction

Shipping, ports and logistics are relevant sectors for the evolving dynamics of today's global economy. Ports play an essential role for the movement of goods and passengers worldwide and, therefore have to respond effectively to the challenges imposed by sustainability, efficiency, security and safety aspects (Gerrero-Molina et al., 2024; Li et al., 2023). Italy ranks first in Europe in terms of passenger and cargo handling, respectively, with 61.4 million passengers and 490.1 million tons of freight transported in 2022 ("SRM & Assoporti - Port Infographics 2023," n.d.; "Trasporto marittimo - Anni 2019, 2020, anticipazioni gennaio-settembre 2021," 2022). Italian ports are strategically and geographically well located in the center of the Mediterranean, enjoying advantageous access for important trade routes. Maritime passenger transport, whose purposes include tourism, as seen in Ciacci et al. (2023) and Spinelli et al. (2024), is fundamental for the Italian territory. The presence of numerous islands requires efficient and sustainable maritime services, with an adequate level of frequency and coverage, especially for island inhabitants. It is also important to take into account the seasonality of passenger service, which is characterized by concentrated peaks during holidays and the summer months. In this context, the study of transport networks and port interconnections plays a key role. In complex systems, the connectivity between elements is a crucial characteristic. Graph Theory and Network Analysis allows the description and analysis of physical interactions between the elements of a system, such as the nodes of a port network according to Ducruet (2020). Several models have been developed over the past two decades to evaluate different networks and modes of transportation, using the concept of centrality and emphasizing point-type infrastructure such as airports and ports, as seen in works of Brito et al. (2021) and Tesoriere (2023). The application of Graph Theory to maritime transport is first defined by Robinson, (1968), by defining a maritime transport network through nodes (the ports) and arcs (the relationships between them). Network analysis has been slow to establish itself in the maritime field, at least until the 2010s, according to Ducruet (2020). The research conducted by Kanrak et al. (2019) considered social network analysis models to maritime networks, where ports are nodes connected by shipping services.

The study shows that the importance of an individual node in the network can be assessed using various measures of centrality, including degree, betweenness, proximity, and eigenvector centrality. Network analysis turns out to be fundamental when the connectivity of ports is to be studied and hierarchies among them are to be defined, according to Ducruet et al. (2021). Today, Network Analysis is mainly applied to the freight context; consider the work of Brandão et al. (2020) and Wang et al. (2022). Some applications are proposed for the study of container traffic, as in Čišić et al. (2007), Frazila and Zukhruf (2015) and Wang and Cullinane (2016), for the evaluation of the efficiency of a port throughput, as suggested by Kim and Lu (2015), and for assessing the vulnerability of port networks, as in the contribution of Lhomme (2015). Regarding passenger traffics, a much lower number of works can be found in the literature, such as Achmadi et al. (2021), Makkonen et al. (2013) and Tsiotas and Polyzos (2015), related to the accessibility of smaller islands. In Graph Theory and Network Analysis, the concept of centrality is used to determine the most important node in a network. Centrality indicators assign numbers or rankings to nodes within a graph, based on their position in the network.

The objective of this research is to apply a centrality analysis, based on 3 indicators, to maritime passenger services related to the Tyrrhenian-Ligurian basin, consisting of 18 ports, located in Italy and France. The research contribution concerns the use of a set of indicators that consider elements such as distances, which have rarely been examined in the literature, as well as the application of network analysis to the passenger transport service of a maritime basin not yet investigated. The three indicators refer to the total number of connections, the number of services present, and the distances covered. The proposed indicators allow to analyze connectivity as an element of the supply system and to understand an initial hierarchy of the nodes of the network. As such, the indicators considered are a component of the possible analysis referring to accessibility. Research on connectivity in passenger transport has various implications. Among these, the possibility of identifying less served nodes in the network and assessing service levels for smaller islands for which, following further investigation, more connections may be needed. The results obtained made it possible to better outline the transport supply framework of this basin with the aim of guiding policies aimed at planning services with a view to improving maritime connections. The present study shows a seasonal trend

throughout the year, with more connections in the summer months, in line with the tourist nature of the connections analyzed. The indicators taken into account reveal: a network with few interconnections, the centrality of the Tuscan archipelago, and, if the distances covered are also considered, Bastia turns out to be the most relevant port among those considered.
This research is structured as follows: Section 2 describes the methodology used in the study while Section 3 identifies the case study considered. The results achieved and related insights are explained in Sections 4 and 5, respectively. Finally, section 6 is dedicated to conclusions and outlining possible lines of future research.

## 2. Methodology

All The methodology used in the present work to study a Ro-pax maritime network consists of the following methodological steps:

1. *Data acquisition*, involves defining the study area and passenger ports under consideration. Assuming $i, j$ are two generic ports that refer to the study area, all services $s_1(t), s_2(t), \dots, s_k(t), \dots, s_n(t)$ that, in a given time interval $t$, connect at least one pair of ports $(i, j)$ are identified.
2. *Data elaboration*: the relationships between the pairs of nodes $(i, j)$ are considered. Starting with $s_k(t)$ services, the graph of relationships is then defined using the adjacency matrix $A_{ij}(t)$ composed of $a_{ij}(t)$ elements:

$$a_{ij}(t) = \begin{cases} 1, & \exists s_k(t), i \to j \vee \exists s_k(t), j \to i \\ 0, & otherwise \end{cases} \tag{1}$$

3. *Network indicators computation*: three connectivity indicators are identified and calculated, based on Iapadre and Tajoli (2014) and Kanrak et al. (2019): Total Degree centrality, Strength centrality on Frequency, and Strength centrality on Routes explained below. Degree centrality $c_i(t)$ and strength centrality $s_i(t)$ were considered as parameters for calculating and comparing the results. While degree centrality is a topological measure of the network, the proposed strength centrality considers frequencies as weights for each relationship. In the case of medium-sized basins, where medium-distance routes and long-distance routes coexist, it is possible that some nodes may be subject to bias in centrality due to high frequency. This happens for instance in relation to the connections of smaller islands or connections between islands and the mainland or to/from larger islands. The third indicator is then introduced, which analyzes the summation of the input and output journeys of each node. This third indicator is in the category of Strength centrality, because the relationship between two nodes $i$ and $j$ is weighted. However, it introduces distances. Therefore, in the following, we refer to this third indicator as Strength Centrality on routes.

***First indicator -*** "Total Degree centrality"
The indicator of Total Degree centrality measures the degree of connectivity of a port within the network it belongs. It allows defining, for each node *i,* the total number of nodes with which $i$ is connected, relative to the $N$ nodes in the graph. It is defined as:

$$c_i(t) = \frac{\sum_j a_{ij}(t)}{N-1} \tag{2}$$

***Second indicator -*** "Strength centrality on Frequencies"
The strength centrality on frequencies indicator associates each link $(i, j)$ with a weight $w_{ij}$ , allowing the link to be hierarchized. The weight $w_{ij}$ is defined on the basis of the frequency of the links between the nodes $i$ and $j$ at time $t$.

$$s_i(t) = \sum_j w_{ij} a_{ij}(t) \quad (3)$$

This second indicator makes it possible to highlight the presence of nodes with a greater number of connections. In the maritime context, the presence of nodes connected with a few other nodes but with high frequencies is common. This is, for example, the case of smaller islands connected to a main port on the mainland. It is not unusual, especially in medium-sized basins, the coexistence of medium-distance flows (in the range of hundreds of nautical miles) and short-distance flows (in the range of tens of nautical miles).

The proposed indicators do not consider additional elements beyond the frequency and topology of the network.

When different nodes have similar values of $c_i(t)$ (number of relationships served) and $s_i(t)$ (frequency of links), distortions may occur and is therefore necessary to introduce another element to provide further hierarchy of nodes, and thus of relative centrality. Consider, for example, a minor island $i$ connected to a main port $j$ on the mainland; it might have a low value of $c_i(t)$ but a high value of $s_i(t)$, because of the considerable number of services. Strength centrality on services alone would return a very high value resulting from the existence of a single relationship (i.e., between minor island i and main port $j$). Sub-systems may exist having much higher frequencies than the system average. This is the case of archipelagos or realities where maritime transport is necessary to ensure territorial continuity, or the absence of other modes of transport. As a further element of hierarchy on the network, therefore, the distance covered by the generic service should be considered.

***Third indicator - "Strength centrality on distances"***

It is assumed that, in a medium-sized basin, for passenger traffic, the frequency of connections $(i, j)$ is inversely related to the distance between $i$ and $j$ (as the distance increases, the routes that an operator can operate in the same time interval decreases). Therefore, a third indicator of centrality $l_i(t)$ (strength centrality on distances) is introduced. It is equal to the sum of nautical miles traveled by incoming and outgoing ships for passenger transport in the port under consideration at the time considered, as follows:

$$l_i(t) = \sum_k s_k(t) \delta_{i,k} * d_{s_k} \quad (4)$$

where:
$d_{s_k}$ is the distance travelled for transport service $s_k(t)$, expressed in nautical miles;
$\delta_{i,k}$ equals to 1 if $s_k(t)$ makes a stop in $i$, 0 otherwise.

## 3. Case study

The methodology described in Section 2 was applied the maritime services referring to the year 2024 for the Northern Tyrrhenian ports/Ligurian Sea/Cote d'Azur, using data from ferry services made available on the websites of Port System Authorities and shipping companies. This basin refers to the Italian regions of Liguria and Tuscany and to the French island of Corsica. In Ligurian regions are located very important Italian ports: Genoa (which is the most relevant one), Savona and La Spezia play at an international level, while a multitude of smaller ports are devoted to satisfy local needs. Liguria is a region affected by intense tourist traffic.

This is due to popular seaside resorts, a widespread network of marinas, valuable natural resources and UNESCO heritage sites such as Porto Venere, Cinque Terre or the Palazzi Rolli system in Genoa. The sea economy accounts for 9% of the total in the Liguria region. Regarding passenger traffic specifically, considering both cruises and ferries, Western Ligurian ports moved 5,244,442 passengers in 2023 ("Traffic statistics of western Ligurian ports, 2023," n.d.), while Eastern Ligurian ports (mainly La Spezia port) handled 794,733 in 2022 ("Traffic statistics of eastern Ligurian ports, 2023," n.d.).

Transportation infrastructure and mobility services are, therefore, a relevant factor for competitiveness of territorial systems at local, regional and international levels, and for the quality of urban settlements and logistics. Tuscany has three ports relevant to passenger traffic: Livorno, Piombino and Porto Santo Stefano. From the port of Piombino, which faces the archipelago of the Tuscan islands, ferries leave for Sardinia and Corsica, two very large islands on the other side of the Tyrrhenian Sea. The remaining ports are located on Elba Island and on smaller islands, which are involved in a significant flow of tourists in the summer months. The port of Livorno is connected to Sardinia, Corsica, Spain, Morocco and the Island of Capraia. Tuscan ports as a whole handled 9,559,266 passengers in the ferry sector in 2023 ("AdSP traffic statistics, 2023," n.d.).Corsica is well connected by sea with France, nearby Sardinia and major Italian ports. In 2023 it handled a total of 4,327,633 passengers ("Traffic statistics of Corsican ports, 2023," n.d.). The island's main ports are Bastia, Ile rousse and Calvi in the north and Ajaccio, Propriano, Porto Vecchio and Bonifacio in the south. Several French and Italian companies offer Corsica - France ferries operating on routes from Nice, Marseille and Toulon to the ports of Bastia, Ajaccio, Propriano, Calvi and Ile rousse. The following shipping companies operating in the selected area were considered in this research: La Meridionale, Corsica Linea, Corsica Ferries, Moby, Toremar and Blue Navy. There are 21 ports connected in the network, but three ports have been removed: the port of Sete, due to the small and thus not significant number of services, and the ports of Giglio and Porto Santo Stefano, since they are connected by services linked together and disconnected from the rest of the network.

## 4. Results

The services selected for this research were analyzed by considering, as a reference, the average monthly number of services per week. This value was chosen because:

- the number of connection services shows high variability within the week;
- the number of connection services shows little variability (only erratic, it would seem) between week and week but within the same month;
- the number of services varies greatly from month to month.

Using this information, it was possible to rebuild, for each pair of nodes $(i, j)$, the number of services connecting $i$ to $j$ for each "typical week" of the month. For each month $t$, if two nodes $(i, j)$ are connected by at least 1 weekly service, they are considered adjacent. Figure 1.a shows the locations of the ports considered in the study. Figure 1.b shows the trend of the average total number of weekly services in the year 2024 for the ports considered in the study. The month of August is significant because it is the period when the average number of services peaks. This is mainly due to the nature of the islands in the area, poles of attraction for resort tourism, which generates considerable seasonality in the system. Figure 2 shows the graph of maritime relationships in the considered basin.

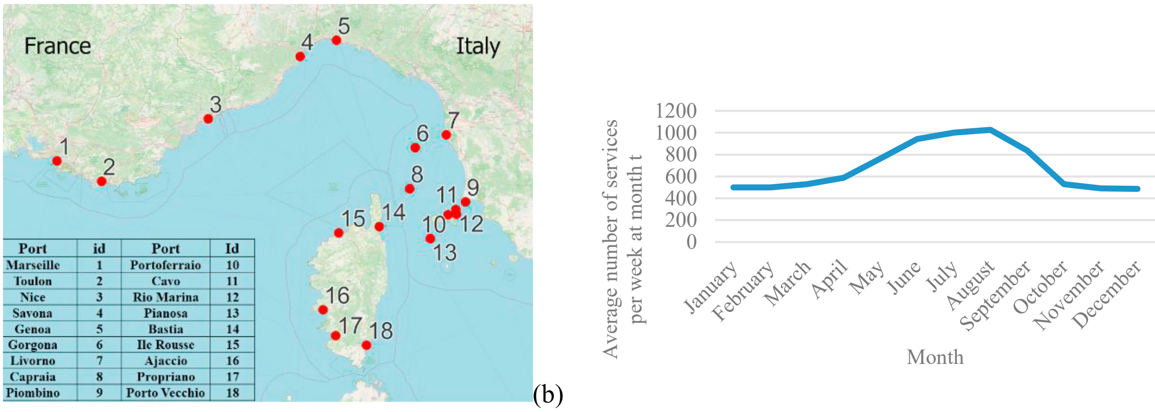
(a)  (b)


Fig. 1 (a) Port locations; (b) Evolution of number of services during the year 2024

The graph presented in Fig.2 shows the typical "star" network composition, in which nodes aggregate around local centers. It is possible to note two subsystems, i.e., Piombino-Elba-Pianosa and Livorno-Gorgona-Capraia, while the other nodes (Corsica, continental France, and the other Italian nodes) are connected according to a less defined pattern

in which the center is Bastia. The Bastia node has the function of integrating all subsystems: the France-Corsica-Liguria subsystem, the Livorno-Gorgona-Capraia subsystem, and the Piombino-Elba-Pianosa subsystem.
The formulas for calculating the values of $c_i(t)$ and $s_i(t)$ were applied based on the relationships shown in Section 2. Fig. 3 show the values of the three indicators considered.

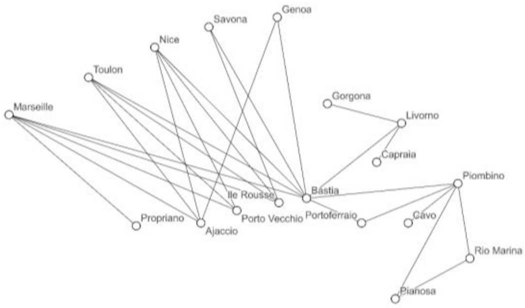



Fig. 2 Graph of the passenger maritime services within studied area

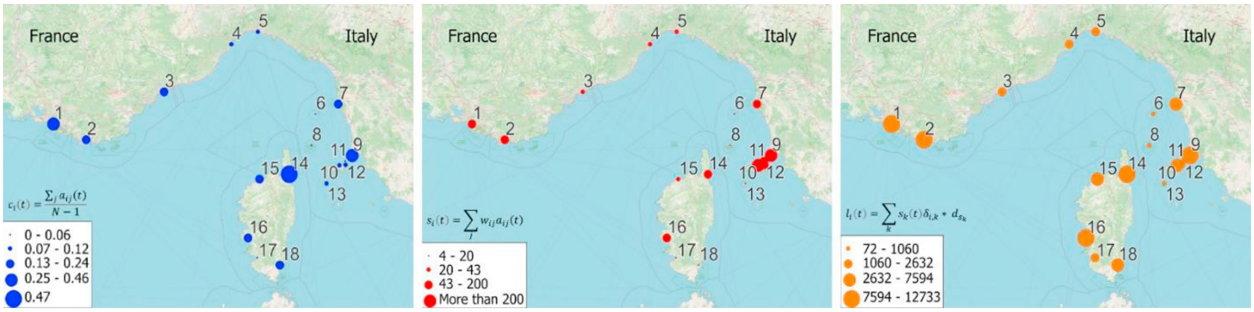



Fig.3 Network analysis and relative indicators. Identification of ports and their IDs refer to the table in figure 2(a)

Since none of the calculated values of $c_i(t)$ exceeds 50 %, it means that there are no leading nodes in the considered network. The distribution of $c_i(t)$, shown in Fig. 4, is a flat trend: there are many nodes with a small number of connections. 90% of the nodes have a value of $c_i(t)$ less than 0.35, showing a sparsely interconnected network with no nodes with hub roles. The highest value of $c_i(t)$ is equal to 0.47 and is reached by the Bastia node, assigning centrality to Corsica. Other significant nodes turn are Piombino, Marseille, Nice and Ajaccio.

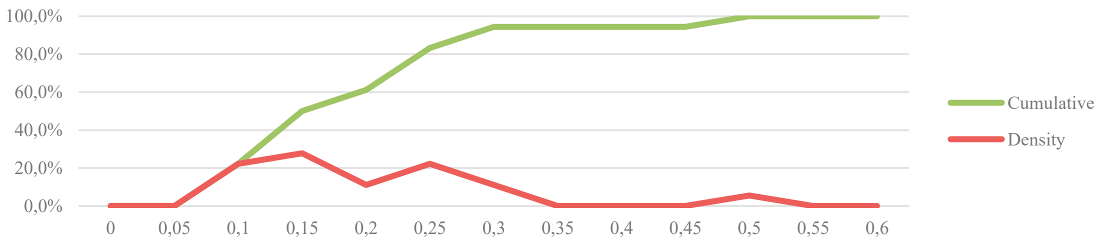



Fig. 4 Distributions of $c_i(t)$ indicator

In contrast, the trend of the $s_i(t)$ indicator shows a different pattern. It shows high values for Bastia (134.4), Livorno (63.2), Ajaccio (52.8), and Marseille (56). In addition, ports in the Piombino-Elba system show even higher values of $s_i(t)$: in particular, Piombino has a value of 706.3 and Portoferraio 552.4. These values are an order of magnitude higher than those, albeit high, of the mainland ports considered earlier. This is due to the large number of connections present on a weekly basis to ensure territorial continuity between the island of Elba and the mainland. The Piombino-Elba subsystem therefore shows higher average $s_i(t)$ values than the rest of the network, due to the need to guarantee stable connections between Elba and the mainland, the reduced maritime distances that allow to increase services' frequency, the presence of tourist flows and the absence of airports on the islands considered. These elements generate an asymmetry in the system that, evaluating only $s_i(t)$, shows a significant increase in the values of minor ports. The proposed $l_i(t)$ indicator refers to the Strength centrality indicator categories, by considering not only frequency but also nautical miles as a weight, offering a result that compensates for the asymmetry generated by frequencies in basins such as the one considered.

## 5. . Discussion

The network considered has a structure composed of two interconnected subsystems: the Corsica-North Shore subsystem and the Tuscan Archipelago subsystem. In addition, the network presents a star shape around the node of Bastia, which is the main passenger port in Northern Corsica. The study shows a seasonal trend throughout the year, peaking in the summer months, marking the tourist nature of the links considered. The values of the total degree centrality indicator and its distribution show a network with few interconnections. In the month of August, the node with the highest $c_i(t)$ value, namely Bastia, shows a value of 0.47. Other significant nodes are Piombino (0.29), Marseille (0.29), Nice (0.24) and Ile Rousse (0.24). 90 % of the nodes show a value of $c_i(t)$ less than 0.35; this indicates a poorly interconnected network, in which there are many nodes with few connections. The strength centrality indicator $s_i(t)$ shows higher values (over 700 relations/week for Piombino, over 500 for Portoferraio) for the Tuscan archipelago area.

This is due to the need for territorial continuity and the absence of airport hubs in the considered islands. $s_i(t)$ is also high for some nodes in Corsica; in particular, Bastia is the node with the highest value of $s_i(t)$, equal to 134. Finally, the calculation of the strength centrality indicator on distances $l_i(t)$ suggests weighting the number of services entering/exiting port $i$ by the nautical miles traveled.

Taking into consideration the total distances in and out of a port, the most relevant port is Bastia (over 12,000 nm), due to the presence of relatively high-frequency, medium-distance connecting services. The other important nodes according to this indicator are Marseille and Toulon (about 10,000 nm), while the port of Piombino ($l_i(t)$ =7798 nm) is only fifth for this indicator, behind Ajaccio (about 8000 nm). The methodology adopted tend to "punish" Italian ports, particularly Genoa, which also have routes to the central and southern Tyrrhenian Sea. This approach in fact does not consider other supply elements (time, cost), demand elements (such as population) and additional aggregate elements (such as macro-economic elements). It studies connectivity as an element of the supply system and proposes an initial hierarchy of the network. As such, the indicators considered can be a component of accessibility, which needs further investigation.

## 6. Conclusions

The aim of the present study was to assess the centrality of passenger ports of an important European maritime basin, located between France and Italy, which connects the continent with a large island, Corsica, and several smaller islands. A 3-indicator methodology applied to the indicated case study was used, which allowed the ports to be classified according to the presence of services, the frequency of service and the distance covered by the service. The results obtained revealed that the network considered is a disconnected network, serving mainly the needs of islands. The results also show a relatively marginal role played by Italian ports. The analysed case study has some homogeneities and can be divided into interconnected sub-systems. The Strength centrality indicator on frequencies highlights a higher centrality for ports connected to smaller islands, which are often provided with more frequent connections, due to the absence of alternative modes of transport and shorter distances. The Strength centrality indicator on routes, which introduces the nautical miles travelled by carriers, returns a centrality value that balances the asymmetry introduced by the indicator previously described. This research can be useful to both public administrators and managers to better plan maritime transport services. Research can also help in the management of on-shore services for the improvement of city port connections in terms of more efficient and sustainable mobility (e.g. the use of complementary services to public transport such as DRT). Future research will be devoted to extending the study to the entire Tyrrhenian basin and other island basins (e.g., the Balearic Islands), or to other connections (North African Ports), evaluating the inclusion of demand elements for a more comprehensive study of the sea-side accessibility of these locations, and carrying out a comparative study that also considers other modes of transportation.

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