

The Mediterranean Maritime Network of Container Shipping: Spatial Structure and Regional Dynamics

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Abstract. This study proposes to analyze the maritime transport network for container traffic in the Mediterranean Sea basin. For this purpose, the 29 main ports that make up the study macro-region were analyzed by taking into consideration the traffic volumes handled and the main pendolum and round-the-world routes operated by the main shipping companies. These two components represent the nodes and arcs of the studied network, on which a subdivision of the different ports was then made based on their geographical location and different ranges of belonging. To fully understand the transport dynamics, Freeman's centrality indices and Eingivenvector Centrality were successively introduced, which are useful in capturing which nodes are the most relevant within the transport network and in defining possible lines of future development for the sampled ports. In this context, the main transshipment hubs located along the Port Said - Gibraltar backbone assume an increasingly relevant role while, in the face of an increasing decentralization of secondary transshipment hubs. Moreover, this analysis highlights how gateway ports that direct their flows not only to the back-port area but also to other ports, assuming the role of mixed ports, are consolidating an increasingly prominent position of centrality.

Keywords: Network Analysis · Mediterranean Sea · Maritime Transport · Transport Dynamics · Regional Structure

1 Introduction

There are three basic dimensions in the study of transportation geography: flows, nodes and transportation networks. In this complex system, ports represent the fundamental nodes of transport networks [1].

In this paper we propose to analyze network dynamics in relation to containerized maritime transport in the Mediterranean Sea basin, relating the Ports, as nodes in the port system and from the main pendolum and "round-the-world" routes operated by major shipping companies [2]. We can see how the Mediterranean basin is spotted with a multitude of different ports, from established major ones, to a wide range of medium and small ports, each with specific characteristics over which different locational and

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strategic dynamics intersect within the hinterlands served and the different commodity categories handled [3, 4]. This combination of different types and dimensions of ports, aided by the presence of a vast hinterland, has led to the creation of a uniform space that provides a suitable case study for trying to analyze the factors affecting port hierarchy and competition [5]. Several studies have investigated the development dynamics of the different port systems on a regional scale or with reference to individual ports [6], and in particular the dynamics of transport flows in the Mediterranean basin have been studied in numerous works [7, 8]. The contributions mentioned before representing the cornerstones for an in-depth analysis of containerized traffic flows in the Mediterranean Sea area, and in particular, there are several studies that have dealt with the analysis of maritime traffic through complex network analyses: in this sense, the works carried out by Ducruet [9, 10] should be mentioned.

This analysis aims to propose to relate the role that different ports are called upon to play as gateways for traffic to port hinterlands or as transshipment hubs [11]. The second aspect to be considered concerns the relationship between the different port ranges of afferent ports, going beyond the simple concept of a port as a single node of the network, but also taking into consideration the relationships between the different port ranges characterized by contiguous geographic locations and a hinterland sharedness [12, 13]. Finally, the last aspect considered is aimed at taking into account the connections between different ports arising from maritime transport routes, finally sketching the evolutionary profiles that different ports are experiencing. As mentioned, the Mediterranean basin is called upon to play a strategic role in maritime transport on a global scale: its location along the main east-west trade routes, central to the Atlantic, Northern European, Asian, and African markets offers significant connectivity advantages to shipping companies, enabling a reduction in transit time and an important channel of access to markets in continental Europe and the Middle East [14, 15].

However, this contribution was designed and executed using data and geopolitical circumstances prior to the crisis that has affected traffic through the Red Sea and Suez Canal in recent months, beginning in October 2023. In recent months, numerous missile attacks have been launched on cargo ships by the Yemeni Houthi armed group linked to the Israeli-Palestinian conflict. As a result, the considerations and achievements currently seem obsolete. However, given the crucial role of the Suez Canal in global traffic, through which roughly 12 percent of the world's trade was transiting[1], it can be expected that the situation may return to a state close to normal in the near future.

This article considers 29 ports located within the Mediterranean Sea basin, with the intent of identifying the main development trajectories of the port system of the region.

2 Data Collection

The Mediterranean Sea has a role of great importance as a natural artery for trade flows connecting the Far East to continental Europe. This vast maritime area is bounded by two critical points known as "choke points": the Strait of Gibraltar to the west, which is called upon to fulfill the role of a bridge with the Atlantic Ocean, and the Suez Canal to the

[1] Source: https://unctad.org/news/red-sea-black-sea-and-panama-canal-unctad-raises-alarm-global-trade-disruptions, last access: 12 march 2024.

southeast, which constitutes the most efficient route for handling the movement of goods on the east-west route [16, 17]. Its strategic position within the global macroeconomic landscape makes it a vital crossroads for supplying markets and manufacturing districts in continental Europe, even in relation to supply markets in the Middle East. The importance of this maritime region is reflected in the complex and intricate port network that has developed in response to this need. The port infrastructure along the Mediterranean coast has been carefully planned and developed to facilitate the efficient movement of goods and smooth international trade.

These characteristics have generated a steady increase in the traffic volumes operated by the different ports, rising from a share of about 34.9 million TEU in 2010 to 50.7 million in 2022 with reference to the sample under analysis.

To study the evolution of the dynamics of containerized traffic in the Mediterranean Sea, the traffic volumes for individual ports, presented in the summary table below (Table 1), were considered, and a categorization of the 29 nodes in six different port ranges was subsequently made:

- Spanish Med Range (Barcelona, Valencia, Algesiras);
- Ligurian Range (Genoa and Vado Ligure, La Spezia, Livorno and Marsille Fos);
- North Adriatic Range (Trieste, Venice, Ravenna, Ancona, Koper and Rjieka);
- Central Mediterrean Range (Gioia Tauro, Naples, Cagliari, Taranto, Malta Freeport and Tunis (Rades));
- East Med Range (Piraeus, Thessaloniki, Izmir, Mersin and Ambarli);
- South Med Hubs (Limassol, Port Said, Damietta, Alexandria and Haifa).

Table 1. Transport Volume and Main Services and Range of affiliation for Mediterranean Ports.

Port ID	Main Service	Range	2010	2022
Port of Piraeus	Transshipment	East Med Range	885,155	5,311,810
Port of Tessaloniki	Gateway	East Med Range	273,131	470,645
Port of Valencia	Mixed	Spanish Med Range	4,206,937	5,052,272
Port of Algeciras	Transshipment	Spanish Med Range	2,806,884	4,767,282
Port of Barcelona	Mixed	Spanish Med Range	1,931,033	3,522,944
Port of Marseille	Gateway	Ligurian Range	953,435	1,530,000
Port of Rjieka	Gateway	North Adriatic Range	137,048	520,866
Port of Genova	Gateway	Ligurian Range	1,955,292	2,799,123
Port of Gioia Tauro	Transshipment	Central Med Range	2,852,264	3,380,053
Port of La Spezia	Gateway	Ligurian Range	1,285,155	1,262,496
Port of Livorno	Mixed	Ligurian Range	628,489	751,811
Port of Trieste	Mixed	North Adriatic Range	281,643	877,805
Port of Venezia	Gateway	North Adriatic Range	393,913	533,991

(*continued*)

Table 1. (*continued*)

Port ID	Main Service	Range	2010	2022
Port of Napoli	Gateway	Central Med Range	534,694	684,111
Port of Cagliari	Transshipment	Central Med Range	629,340	140,216
Port of Ravenna	Gateway	North Adriatic Range	183,577	228,435
Port of Ancona	Gateway	North Adriatic Range	110,395	165,346
Port of Taranto	Transshipment	Central Med Range	581,936	26,269
Port of Marsaxlokk	Transshipment	Central Med Range	2,370,729	2,890,000
Port of Koper	Gateway	North Adriatic Range	476,731	1,017,798
Port of Tunis	Gateway	Central Med Range	420,089	258,716
Port Haifa	Gateway	South Med Hubs	1,263,000	1,491,180
Port of Izmir	Gateway	East Med Range	695,799	390,274
Port of Mersin	Mixed	East Med Range	1,250,873	2,059,309
Port of Ambarli	Gateway	East Med Range	3.023.960	2.867,215
Port of Limassol	Transshipment	South Med Hubs	382,000	384,000
Port Said	Transshipment	South Med Hubs	3,627,813	4,764,583
Port of Alexandria	Transshipment	South Med Hubs	812,446	1,488,436
Port of Damietta	Transshipment	South Med Hubs	1,214,910	1,106,151

Source: Personal Elaboration on different Port Authority Data

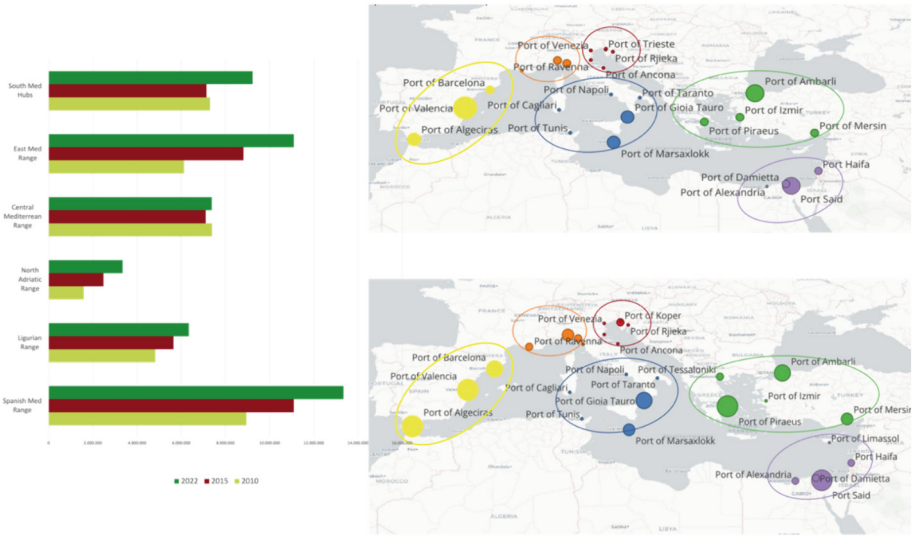

Fig. 1. Different Port Ranges and traffics in Mediterranean Basin. Source: Personal Elaboration

Finally, the last aspect to be considered in this analysis concerns the main routes operated by the major shipping lines. At this juncture, the information provided by the reports of the major Shipping Companies regarding pendolum routes aimed at linking continental European markets with key destinations in the Far East and North American markets in relation to continental flows in the Mediterranean Sea has been summarized [2] (Fig. 1).

This analysis is structural in order to try to understand there is a relationship between the strategic investment choices in the different terminals and the choices proposed by the different Shipping Companies regarding the choices of ports on which to call.

The main routes operated are presented in the figure below (Fig. 2).

As extremely complex as the transport network appears, we can see that the Port of Piraeus is included by only one of the ocean routes under analysis with regard to MSC trades while it is completely excluded with regard to the main routes operated by Maersk. In contrast, the trades operated by the 2M alliance make extensive use of the Algeciras and Gioia Tauro container terminals. Another relevant consideration is related to the strategic importance of the port of Marsaxlokk with regard to the main routes operated by CMA-CGM, which, however, tend to avoid pendolum connections with the port of Algeciras [2, 18]. Conversely, the port of Gioia Tauro is not included in the calls operated by Cosco and Evergreen. We can also observe that there is an important concentration of traffic volumes on the port of Piraeus by the three Ocean Alliance member companies such as CMA-CGM, Cosco and Evergreen. These considerations, however, are treated in the light of evidence related to the Mediterranean trades as a whole: the transport network appears to be extremely dense and complex for the entire Mediterranean region, in which the different shipping companies try to exploit the synergistic advantages derived from a complex system of gateway and transshipment nodes [19].

3 Method

Understanding the dynamics of transportation in the Mediterranean basin must be treated through an organic and systemic analysis of the different ports and its complex set of interactions. With this in mind, the methodological apparatus used requires, first of all, that the proximity matrix W be constructed for the different nodes of the transport network: this binary matrix represents the proximity relationship between the elements of the system. However, it must be specified that at this juncture, the adjacency matrix was not constructed using the geographic proximity criterion [20]. The W matrix we are going to use was constructed from the analytical reconstruction of the routes proposed in Fig. 4, through which the proximity between two nodes in the network was determined on the basis of a second-degree k nearest neighbor. This thus implies that node Ni and node Nj will have a value of 1 if in one of the routes proposed by the shipping companies, the two nodes can be reached within two calls from the route. In case the distance is greater than the two ship stops, the value will be 0. Thus, this analysis makes it possible to relate what are the main nodes in the system (ports) and the different arcs (routes), from which the proposed methodological apparatus can be expanded [21].

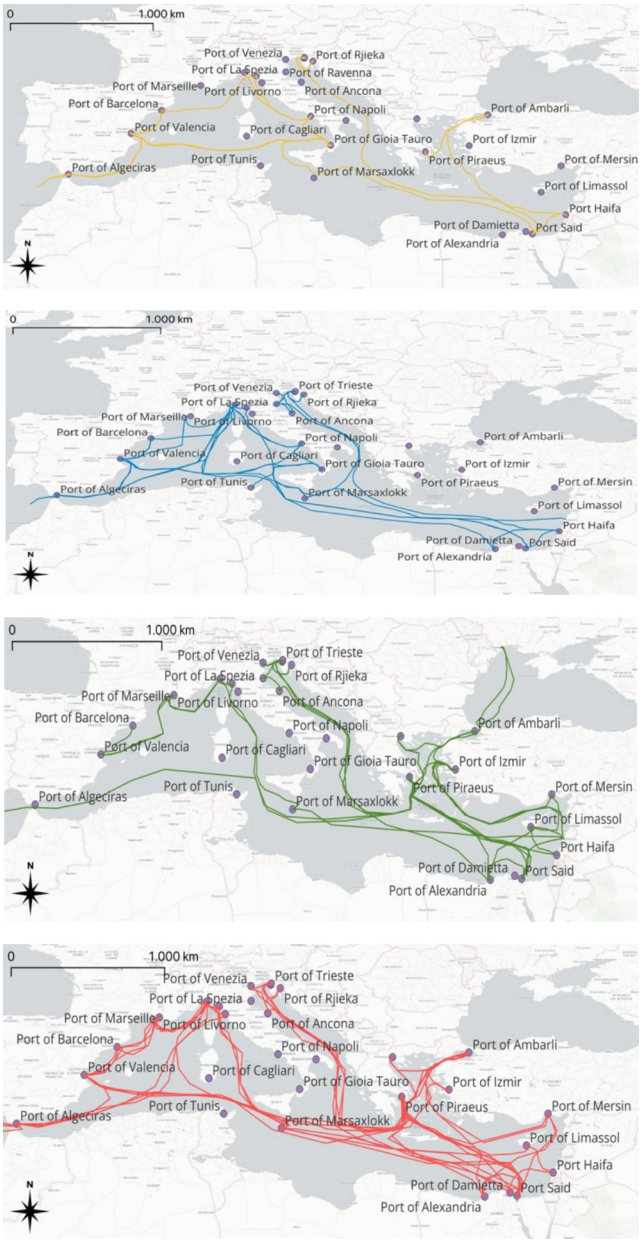

Fig. 2. Main "Pendulum" and "Round the World" routes of the main shipping companies (MSC routes - Fig. 2A), (Maersk routes - Fig. 2B), (Evergreen routes -Fig. 2C), (COSCO routes - Fig. 2D), (CMA CGM routes - Fig. 2E), (Overall routes - Fig. 2F). Source: Author's personal elaboration on Personal elaboration on shipping companies report (Data collected from the web pages of different port operators: https://ss.shipmentlink.com/tvs2/jsp/TVS2_LongTermMenu.jsp?type=L Evergreen; https://www.msc.com/-/media/files/msc-cargo/msc-solutions/trades/transatlantic-med.pdf, https://www.msc.com/-/media/files/msc-cargo/msc-solutions/trades/east-west-network/asia-europe-network_may-2023-cii.pdf MSC; https://lines.coscoshipping.com/home/Services/route/16 COSCO; https://www.cma-cgm.com/products-services/line-services/ CMA CGM; https://www.maersk.com/local-information/shipping-from-europe-to-asia-pacific Maersk.).

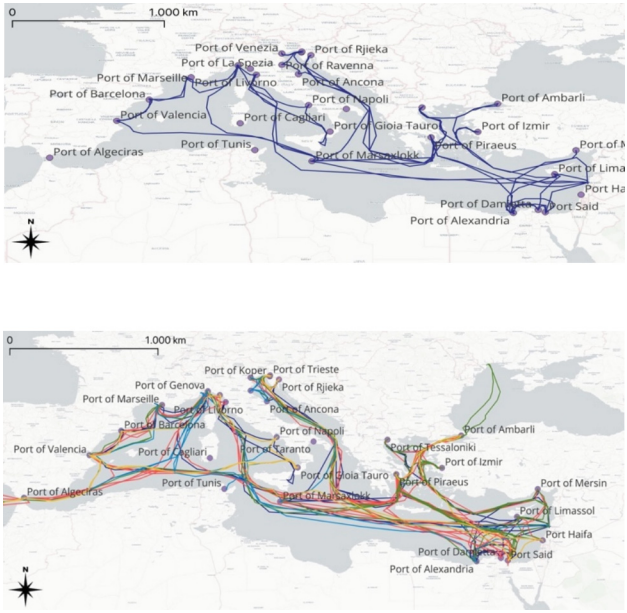

Fig. 2. (*continued*)

By first obtaining the contiguity matrix that determines network development, it is possible to go on to develop Freeman's Degree Centrality Index using the following formula [22]:

$$DG = \sum_{k=1}^{N} \frac{\alpha(n_i; n_j)}{N-1} \tag{1}$$

In this equation n_i and n_j represents two nodes of the network, and, on the other hand, a represents the arc connecting these two nodes. If the arc is present, and thus the two nodes will result connected to each other, α will have a value of 1, in the case where the two nodes are not connected the arc will have a value of 0.

A second centrality index used is the Eigenvector Centrality Index. This index represents a second measure of centrality used in network analysis to assess the importance of a node within a network. This metric is based on the mathematical concept of eigenvectors of a matrix [23]. The main idea behind Eigenvector Centrality is that nodes connected to important nodes are themselves important. The Eigenvector Centrality algorithm assigns each node a score proportional to the sum of the scores of its adjacent nodes, weighted according to their importance, through an iterative process. In more simple terms, a node has high centrality according to Eigenvector Centrality if it is connected to other nodes that are also central. Therefore, the centrality of a node depends not only on the number of connections, but also on the quality of those connections.

The mathematical form for calculating the Eigenvector Centrality of a node in a network is the following:

$$p_i = \frac{1}{\lambda}\sum_j W_{ji}p_j \tag{2}$$

In this case, p_i, p_j represent the centrality of the eigenvector for the i-th and j-th nodes, while the term W_{ji} represents the element in the i-th row and j-th column of the adjacency matrix W.

The key idea is that the centrality score for a node is proportional to the sum of the centrality scores of the other nodes to which it is directly connected, weighted according to their centrality. The estimation of Eigenvector Centrality was done through the network analysis software Gephi.

Traffic volumes, Freeman's Index of Centrality and Eigenvector Centrality are the main indicators on which to build the network analysis hierarchy highlighting the strategic importance and marginality of different ports within the network.

A further elaboration of the indices just used is given by the introduction of graph diagrams, in which the different ports (nodes) and routes (arcs) will be summarized. The first graphs presented were developed from the Fruchterman-Reingold layout [24], defined through a positioning algorithm whose main objective is to arrange the nodes of a graph in such a way that the nodes connected by an arc are arranged close to each other, while the unconnected nodes are evenly distributed in space, introducing forces of attraction between the nodes connected by an arc and forces of repulsion between all the nodes of the unconnected graph. As a result, connected nodes should be attracted close together, while unconnected nodes should repel outward. In fact, the arrangement that is being created is one in which the most central nodes are represented in a more central area, and as the interactions between different nodes decrease these will be arranged in progressively more peripheral areas.

The last step proposed in this paper is to take advantage of a geographic node distribution layout, in which, through the use of latitude and longitude, it is possible to georeferenced the graph in a cartographic environment, effectively giving the graph a spatial dimension that can be imported into common geographic information tools.

4 Results and Discussion

The preliminary analysis on traffic volumes within the Mediterranean Sea immediately highlights some extremely interesting dynamics regarding the dynamics of containerized traffic in the Mediterranean Sea. Considering the initial clustering of the 29 ports in the sample in the different ranges, it can be seen that the ports of Barcelona, Valencia and Algeciras that make up the Spanish Med Range handle a higher share of traffic than the other clusters, handling 26.3% of total flows in 2022. This subdivision also allows us to note co-me the northern Mediterranean ports, deputed to gateway functions to the different hinterlands are able to convey on average a more limited amount of containers than the transshipment hubs located along the east-west route. In particular, the ports of Gioia Tauro and Marsaxlokk for the Central Mediterranean Range, the port of Piraeus for the East Med Range, and Port Said for the ports that make up the South Med Hubs, represent the driving forces for the containerized flows of the different clusters [25, 26].

It can be seen that the near-totality of the ports under analysis have either maintained their traffic volumes virtually unchanged over the past 10 years or are experiencing an expansive phase.

With this in mind, we can immediately see how two transshipment hubs located in southern or island Italy have seen extremely significant traffic slumps: the port of Cagliari, Sardinia, which has gone from 629 thousand TEUs in 2010 to 140 thousand in 2022 and the port of Taranto, which has gone from over half a million TEUs in 2010 to about 26 thousand in 2022. The reasons for these slowdowns can be attributed to the strategic choices of shipping lines and different terminal operators; however, we can already have indications about the extremely more significant volatility of transshipment hubs compared to gateway ports [18]. This dynamic can be attributed to the very nature of the various gateways serving the production-industrial fabric in the port hinterland areas, thus resulting in the fashion-le shift node of sea-land flows [27, 28]. Next, the network analysis of traffic volumes is presented (Fig. 3) carried out using the methodology presented earlier by utilizing the Fruchterman Reingold layout and using the contiguity matrix and weighting for traffic volumes as the first proxy for the realization of the graphs. This layout emphasizes the centrality of the four main transship-ment hubs located near the pivotal east-west Mediterranean route, Suez-Gibraltar, placing the ports of Gioia Tauro, Marsakloxx, Piraeus, and Port Said in the most central positions.

We can also see that the ports of the Spanish Med Range, despite extremely large volumes of traffic, hold a slightly more defiladed position than the ports mentioned earlier, as does the port of Genoa. This dynamic can be explained by the fact that transshipment hubs handling sea-sea flows will indicatively be characterized by a higher number of

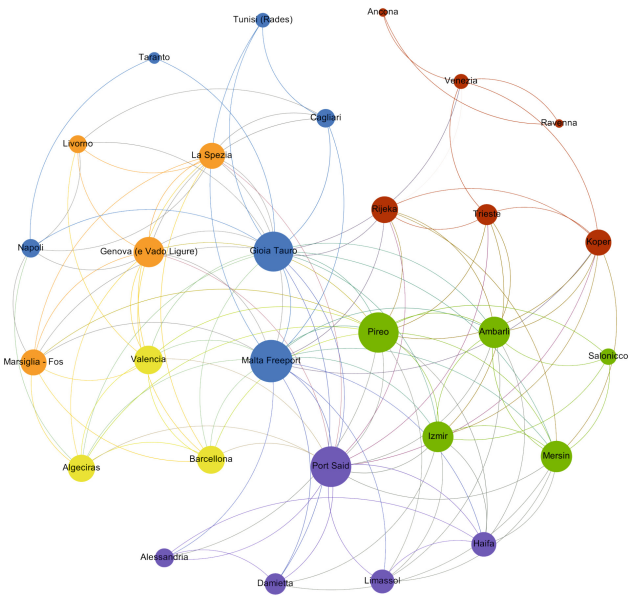

Fig. 3. Network representation of volume of TEU handle per port under the Fruchterman Reingold layout. Source: Personal Elaboration in Gephi.

maritime connections than mixed ports or gateways will move cargo to backport areas [29, 30, 36].

The network analysis was subsequently extended by computing the Freeman centrality index, calculated using Formula (1). Using this indicator, we can see from the graph depicted below (Fig. 4) how there is basically an overlapping with regard to the most central nodes within the port network, but it is interesting to observe how the ports of Algeciras (Spain), Damietta (Egypt) and Ambarli (Turkey) hold rather marginal positions in the face of extremely significant traffic flows. These dynamics are due to different reasons: as far as the port of Algeciras is concerned, infra-Mediterranean routes were considered and not Atlantic ones, nor were the transport dynamics linking the Spanish port of call to that of Tanger Med, a key hub for traffic between the Americas and Europe, and subsequently, for all these ports it must be pointed out that feeder services were not taken into account [31, 32]. Consequently, despite the extremely significant critical mass of these ports, their location within the graph is feeble.

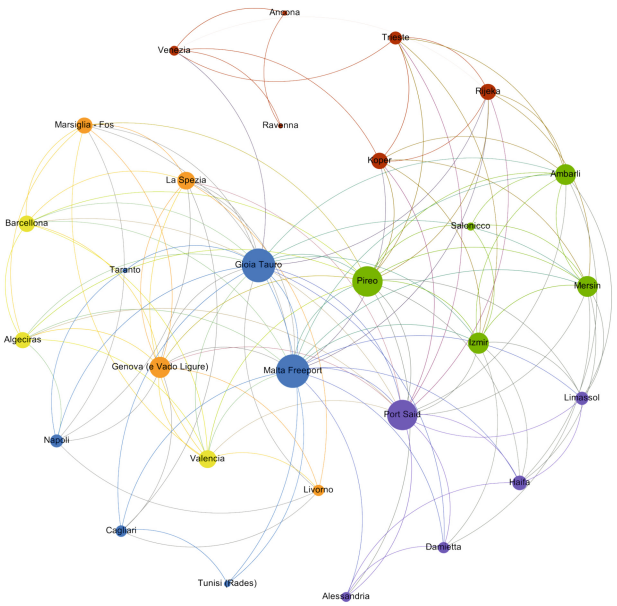

Fig. 4. Network representation of the Freeman Index for the different port under analysis represented with the Fruchterman Reingold layout. Source: Personal Elaboration in Gephi.

Finally, the Eingivenvector Centrality Index provides the extremely accurate representation of the network analysis. This indicator highlights how, partly because of their geographical location, some port ranges play more or less marginal roles within the network, as in the case of the Ligurian Range and North Adriatic Range ports.

In addition, the Eingivenvector Centrality Index highlights how for all the different port ranges, with the exception of the Adriatic range,as presented in Fig. 5, are characterized by the presence of central nodes, represented by transshipment hubs or mixed

ports capable of handling important volumes of traffic, and representing the hub of the transport system on an inter-regional scale [33–35].

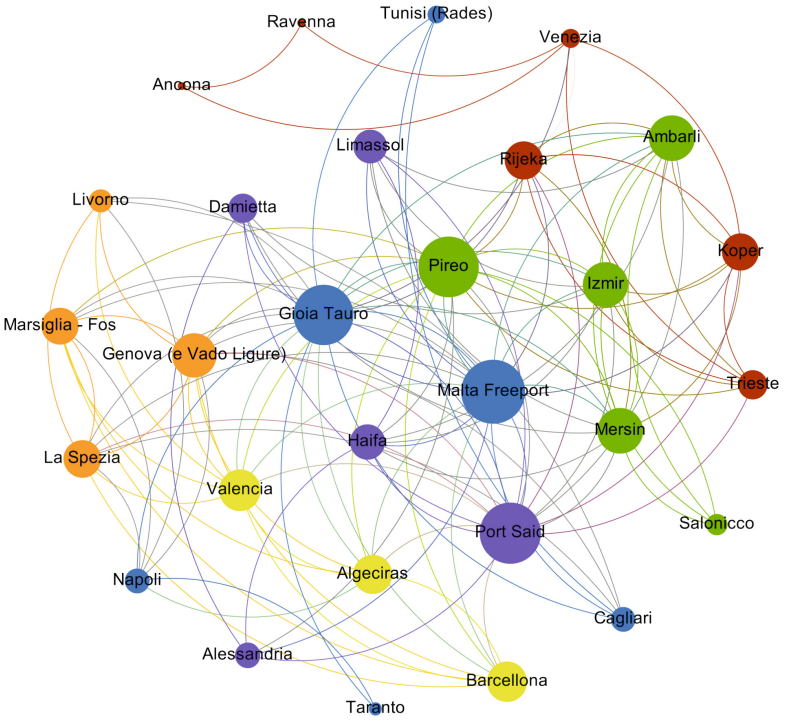

Fig. 5. Network representation of the Eingivenvector Centrality for the different port under analysis represented with the Fruchterman Reingold layout. Source: Personal Elaboration in Gephi.

Finally, using the geo-referenced layer of the network analysis, it is possible to translate these considerations from an abstract Cartesian plane to a map plane. Indeed, in Fig. 6A we find the representation of eingivenvector centrality through the geo-referenced layer, while in Fig. 6B the network analysis related to traffic volumes has been imported onto a thematic map [37].

The map analysis further highlights the ongoing trend of channeling an increasingly significant percentage of traffic shares to strategically located transshipment ports [6, 9]. The strengthening of these ports is also determined at the expense of some hubs, such as the ports of Cagliari and Taranto.

On the other hand, as far as the main gateways are concerned, the overall trend is that of an increase in traffic volumes, but ports capable of conjunctively handling both hinterland and other port traffic, i.e., those ports characterized by the presence of both of these services that take the name of mixed port, are surely destined to assume more central roles within these com-plex networks. This case study certainly includes the port of Valencia, and, to a less marked degree, the port of Trieste [34].

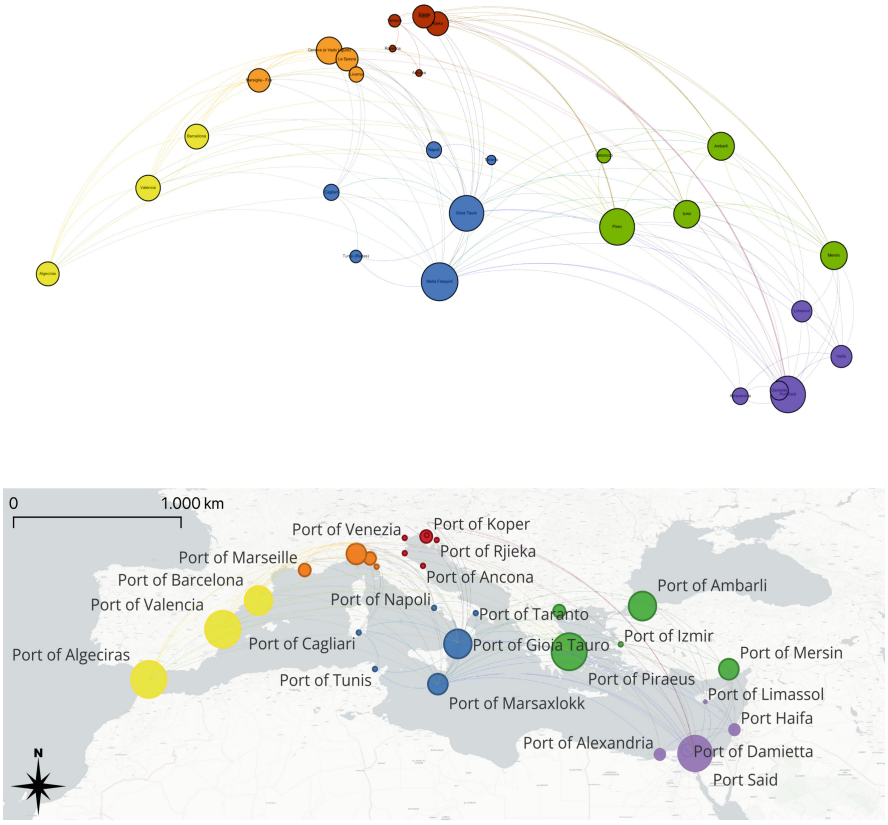

Fig. 6. Network representation of the Eingivenvector Centrality index for the Mediterrenean ports represented by the Geo-Spatial layout (Fig. 6A) and Geo-Spatial layout of the volume of TEU handle by the different ports, imported in a cartographic environment. Source: Personal Elaboration in Gephi (Fig. 6B) and then geo-referenced in QGIS.

5 Conclusion

The Mediterranean port system represents an extremely com-plex and dynamic ecosystem, influenced by the strategic choices of different market players and geo-economic dynamics on a global scale [36]. The complexity of the shipping network in the Mediterranean basin has meant that individual ports no longer represent simple logistics nodes of modal shift of goods [19] but represent strategic pivots of global networks along major supply chains [9]. Market complexity is due to the desire on the part of all market players to want to maximize network effects by exploiting economies of scale wherever possible. These observations justify the trend toward concentration of traffic volumes in a small number of major logistics hubs, which represent the center of gravity of the integrated transportation system not only on a regional scale, but also on a global scale [10].

This analysis shows how the strategic position of the Mediterranean basin in relation to the dynamics of global transportation networks is bound to further increase traffic volumes. We observed how the volatility of traffic volumes for gateways is extremely more limited than for transshipment hubs [14]. For this reason, the development trajectories that the Mediterranean basin will undergo will involve the strengthening of some gateways located in strategic positions with respect to their reference hinterlands, assisted by a growth of the main transshipment hubs located close to the main Mediterranean route, which are characterized by the highest centrality in the transport network. At the same time, we can expect smaller and lesser transshipment hubs to lose their traffic shares due to the centralization of flows to a smaller number of strategic hubs or to gateway ports that are increasing their transshipment share, becoming de facto, mixed ports [19].

The final consideration of this paper regards the actual geopolitical situation that is affecting in this period the Red Sea and the Suez Canal. In fact, since October 2023, the Houthi, an armed group from Yemen, started a series of attacks on merchant vessels navigating into the Gulf of Aden and the Bab El-Mandeb Strait. This ongoing event has led to a restructuring of shipping routes, with cargo vessels now opting to circumvent Africa via the Cape of Good Hope for security reasons. These developments set the considerations presented in this paper outdated, or at least indicative of a transitional period until a return to normal situation. Nonetheless, this events significantly impacts containerized traffic flows within the Mediterranean Sea basin.

Appendix

See Table 2.

Table 2. Freeman Degree of Centrality Index and Eigenvector Centrality Index of the Mediterranean Ports.

Port ID	Degree Centrality Freeman	Eigenvector Centrality	Port ID	Degree Centrality Freeman	Eigenvector Centrality
Ravenna	0107	0.020	Barcellona	0.357	0.579
Ancona	0.107	0.020	Marsiglia - Fos	0.357	0.529
Taranto	0.107	0.107	Rijeka	0.357	0.545
Tunisi (Rades)	0.143	0.194	Koper	0.357	0.524
Salonicco	0.179	0.256	Valencia	0.393	0.603
Venezia	0.214	0.210	La Spezia	0.393	0.533
Alessandria	0.214	0.327	Genova (e Vado Ligure)	0.464	0.652
Livorno	0.250	0.289	Izmir	0.464	0.666
Cagliari	0.250	0.312	Mersin	0.464	0.679

(*continued*)

Table 2. (*continued*)

Port ID	Degree Centrality Freeman	Eigenvector Centrality	Port ID	Degree Centrality Freeman	Eigenvector Centrality
Damietta	0.250	0.394	Ambarli	0.464	0.678
Trieste	0.286	0.390	Pireo	0.679	0.937
Napoli	0.286	0.312	Port Said	0.679	0.949
Limassol	0.286	0.468	Gioia Tauro	0.75	0.929
Haifa	0.321	0.494	Malta Freeport	0.75	1.000
Algeciras	0.357	0.562			

Source: Personal Elaboration

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