# Fostering Ports Synergies by Centrality Measures: An Approach Based on Automated Identification Systems

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**Abstract.** In recent decades, maritime transport is facing a continuous growth generating a rapid development of port infrastructures but also the need to adopt synergy policies between neighbouring ports in order to optimize spaces and resources. In this respect, the knowledge of the main maritime routes and traffic volumes for freight and passenger in each port is essential to establish hierarchies, intervention priorities and to evaluate infrastructure specializations in a planning perspective. In this study an approach based on Automatic Identification System (AIS) is used to build a mathematical model with trajectories vessels between ports, ships classification and traffic volumes, in order to frame a regional network of maritime trades. Network centrality indices are calculated to assess the spatial-temporal characteristics and structure of regional ports' network. The method is applied to the case study of ports located in Sicily, an Italian region characterized by the peculiarity of being an island with more than 1000 km of coasts and a strategic location in the centre of the Mediterranean Sea; both of these characteristics make it a breeding ground for port infrastructure development and terminal specialization.

**Keywords:** Ports centrality · Vessels tracking · Maritime transport network

## 1 Introduction

The recent episode of the blockade of the Suez Canal by an ultra-large container vessel has exposed the fragility of the global economy linked to maritime transport. In particular, this extraordinary event brought two considerations out at the spotlight: on the one hand the importance of maritime transport nodes, even when they are not final destinations of routes but only crossing spots; on the other hand, the importance of a system for monitoring the vessels movement in real time.

In this respect, ports can be considered as the main maritime transport nodes generating several negative impacts, not only in the seaside but also in the landside and in the surrounding urban areas. Understanding how to reduce such externalities by implementing policies which are sustainable both from an economic, social, and environmental point of view is crucial for ports development [1, 2]. Moreover, fostering synergies


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between ports and urban areas, by taking advantage of their coexistence, can play a key role for the sustainable development of cities [3, 4]. The analysis of port activities, indeed, can provide significant benefits not only to the single port, but also in a wider context of network planning. Understanding the importance of a port in the maritime transport network through its connections and the types of traffic can help decision-makers in establishing intervention priorities to ensure the efficiency of the infrastructure.

Based on this premise, this paper proposes an approach for analyzing the centrality of ports based on port calls detected by Automated Identification Systems (AIS) for maritime transport. The aim is to understand the importance of a port as a node within a maritime transport network, regardless of the amount of handled traffic, and to propose potential cooperation policies. The method will be applied to the case study of freight traffic in Sicilian ports (Italy) which are part of a Port System Authority.

## 2 State of the Art

Port networks can be compared to scale-free network [5], so it is possible to characterize them according to parameters related to the theory of complex networks [6]. In the analysis of a transport network through graph theory, centrality indexes can be used as accessibility measures since they allow to get the performance indicator and the level of connection of a node in a system (i.e. the ease to reach it) [7]. Methodologies based on the use of centrality indices provide an important support in transport planning to identify those nodes (airports, bus station, ports) that are strategically located in the transportation system and, therefore, to outline interventions for improving their efficiency [8, 9]. In the maritime sector, Ducruet et al. [10] propose a methodology to describe ports impacts by calculating centrality parameters; they compared the centrality indices with the traffic volume from official port statistics. Results of this study show that traditional data are not always able to accurately describe the characteristics of the network, demonstrating the importance to carry out centrality measures. Brandão et al. [11] analyse the properties and vulnerabilities of Brazilian ports through various centrality measurements (degree, eigenvector, flow betweenness centralities and layer centrality) considering a weighted network. By applying this methodology, the authors realized a ranking of ports in terms of centrality, and they inferred that the most impactful ports were private terminals.

AIS technology can be considered an aid to improve this type of port network analysis, allowing to gather a large amount of data of port calls in short time. The AIS technology aims at providing data related to vessels, such as identification, unit type, speed, position, trajectories, port calls and it is able to coverage the global fleet network in real-time. To transfer AIS data, ships are equipped with an AIS transponder integrated with a VHF (Very High Frequency) transceiver connected to a positioning system (e.g. GPS device). Moreover, there are also other electronic sensors such as a rate of turn indicator and a gyrocompass to acquire information related to the rate of turn and the geographical direction. Initially AIS data were used with the main purpose of reducing ship collisions phenomena and improving navigation safety, but now the fields of application are disparate [12]. There are several studies that addressed port issues by using AIS technology. Perez et al. [13] elaborated a spatial methodology which consists in the exploitation of AIS data to track vessels and then estimate vessel's emissions. Analogue study is that developed by Zhang et al. [14]. They provide a "bottom-up" activity-based model to infer vessel emission by integrating different type of database, not only from AIS, but also from port call registration and field investigation. He et al. [15] propose a data mining process for a more reliable managing of AIS data. After applying this procedure, authors recreated a safe navigation depth-reference map able to reflect the waterway depth and, therefore, to give information for safety navigation. Only a few recent studies propose the integration of AIS data and centrality measures. Wang et al. [16] provide an AIS data-driven approach to extract the global shipping network by taking into account only the container shipping network, using Gephi software. They considered three network levels (i.e. terminal, port and country), and for each level they calculated the number of nodes and links, average degree, network diameter, modularity, average clustering coefficient and the average path length. Sheng and Yin [17] elaborated a clustering algorithm able to calculate the degree centrality to extract shipping routes based on AIS data. Despite these works are focus on the concept of centrality, they did not take into account other specific measures that may be useful for the characterization of a port network, such as closeness, betweenness and eccentricity. The contribution of this work is to provide a methodology which also consider these measures, using AIS to evaluate centrality of ports in a regional network and analyse the potential synergies within port systems.

## 3 Materials and Methods

The approach is based on the following steps (Fig. 1):

1. A portion of data regarding port calls is acquired from the AIS (Sect. 3.1);
2. Data are manipulated to be uploaded in the network topology software (Sect. 3.2);
3. Centrality indexes evaluation is conducted within the software (Sect. 3.3).

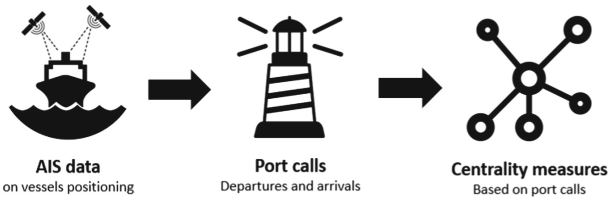


**Fig. 1.** A summary of the used approach

The three steps are described in detail in the following.

### 3.1 Online AIS Services

Several websites provide ship tracking using the AIS to display the location of the vessels and other information, such as route, speed and ship's type. Most of these service providers promise a "real-time" location, but actually the data displayed is always at least some minutes late; so websites are not a proper source to be used during navigation, but they are reliable for research purposes. Online AIS websites generally provides two main type of information: vessels positions and port calls (arrivals and departures). In this study we propose the use of port calls to characterize ports' centrality in a regional maritime transport network. The AIS service generally displays information related to name of the vessel, type of traffic, departure/arrival time for each port call (Fig. 2).

Expected | Arrivals | Departures | In Port

**Recent ship arrivals in Catania**

| Arrival (LT) | Vessel | Built | GT | DWT | Size (m) |
|---|---|---|---|---|---|
| May 6, 13:00 | EUROCARGO CATANIA<br>Ro-Ro Cargo Ship | 2011 | 29429 | 11320 | 193 x 26 |
| May 6, 10:38 | EUROCARGO PALERMO<br>Ro-Ro Cargo Ship | 2010 | 32839 | 10770 | 200 x 26 |
| May 6, 07:39 | EUROCARGO VENEZIA<br>Ro-Ro Cargo Ship | 2011 | 32841 | 10765 | 200 x 26 |
| May 6, 06:50 | ANNE<br>Container Ship | 2007 | 9981 | 11808 | 139 x 22 |

**Fig. 2.** Example of port calls shown on the free AIS provided VesselFinder for the port of Catania (https://www.vesselfinder.com/ports/ITCTA001)

## 3.2 Gephi Software

Once acquired, the data related to port calls are processed through a spreadsheet for the acquisition within the network software. The Gephi software (a free and Open Source software for visualization and exploration of graphs and networks) is used to visualize the topology of the maritime transport network and to calculate the centrality indices. The representation of the network on the software is carried out by means of tables relating to nodes and edges. Nodes table includes an identification number (ID) and a label; in the case of our network, nodes table includes also geographic coordinates of each port; the GeoLayout plugin in Gephi allows a geographical representation of the nodes in the Mercator system (Fig. 3). Edges table tells the software how the nodes are connected, including source node, target node and type of link (directed, undirected). The Gephi plugin Export-To-Earth allows to export the whole network in.kmz format and visualize it in a Geographic Information System (GIS).

## 3.3 Centrality Indexes

Gephi allows the computation of the following centrality indices: (i) Degree, In-Degree and Out-Degree; (ii) Closeness Centrality; (iii) Betweenness Centrality; (iv) Eccentricity.

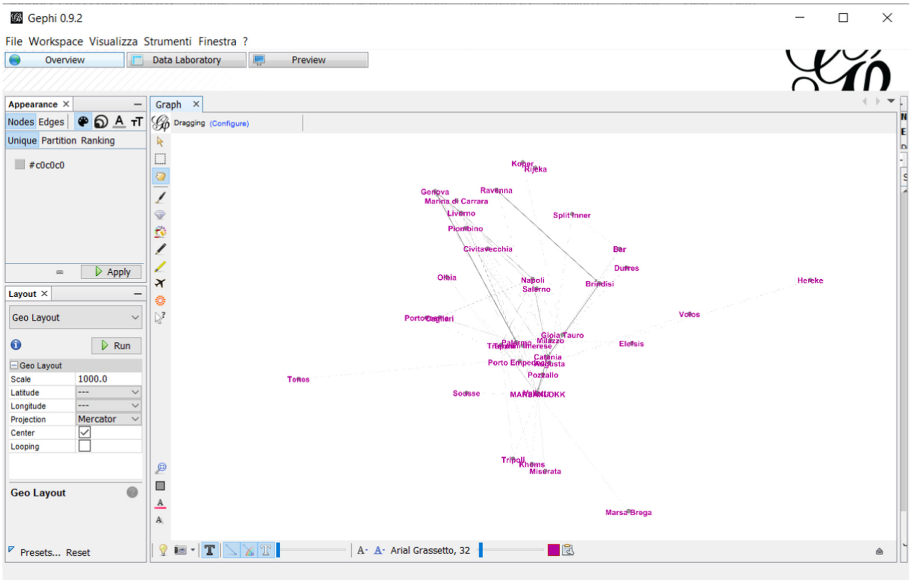


**Fig. 3.** Screenshot of the Gephi interface with a geocoded representation of ports network.

**Degree, In-Degree and Out-Degree (k).** Degree is a centrality measure that counts the number of links (L) incident upon a node (N). In the case of a directed network as the one of our study, one can talk about in-degree (the number of in-coming links) and out-degree (the number of out-going links). In the case of a port network, a high in-degree will mean that a port is a frequent destination of the other nodes in the network.

$$k = \frac{1}{N}\sum\nolimits_{i=1}^{N} k_i = \frac{2L}{N},\ i = 1, 2, \ldots, N \tag{1}$$

**Closeness Centrality ($C_i$).** The Closeness of a node i is the average length of the shortest path between the node and all other nodes j in the graph ($d_{ij}$). The more central a node is, the closer it is to all other nodes. In our case, this shows the directness of links between the ports in the network.

$$C_i = \frac{N}{\sum_j d_{ij}} \tag{2}$$

**Betweenness Centrality ($B_i$).** Betweenness centrality measures the number of times a node lies on the shortest path between other nodes. This highlights the propensity of a port to act as "bridge" (i.e. a stopping point) between origins and destinations.

$$B_i = \sum \frac{d(i)}{d} \tag{3}$$

Where:

– $d$ refers to the total number of shortest paths;

– $d(i)$ refers to the number of shortest paths that lie through node $i$.

**Eccentricity (Ei).** Eccentricity is the inverse of the distance to the furthest node. An eccentricity with higher value means high node proximity. In contrast, if the eccentricity is low, this means that there is at least one node that is located far. This could be considered as a measure of coverage of the port network.

$$E_i = \frac{1}{\max\{d_{ij}\}} \tag{4}$$

# 4 Case Study and Results

## 4.1 Territorial Framework

The approach has been applied to the case study of the Port System Authorities of the Sicily region, in Italy. Since 2016 the Italian port authorities have been grouped into "systems" of ports, in order to promote synergies of operations between neighboring nodes and with the final aim of increasing their overall competitiveness. In particular, three Port System Authorities are active in Sicily: Eastern Sicily System, including the ports of Augusta and Catania; Western Sicily System, including the ports of Palermo, Termini Imerese, Trapani and Porto Empedocle; Strait's System, including the Ports of Messina and Milazzo (in Sicily) and Villa San Giovanni and Reggio Calabria (located in Calabria, and which will not be taken into consideration in this study). The ports forming the different system authorities have very diverse vocations and trades and, consequently, it is easy to hope for synergies of operations.

The port of Catania is mainly a commercial port, in particular for Ro-Ro traffic; this is due to its central position with respect to the city of Catania and its metropolitan area (of about 1 million inhabitants), and its proximity to the main logistic areas of the large food distribution of eastern Sicily. The port of Augusta is part of the TEN-T Core European Network; it is an important industrial pole serving the Syracusan petrochemical center and it is also an important naval base of the Italian Navy; the port also includes an area dedicated to container and Ro-Ro traffic, which is currently undergoing infrastructural improvements.

The port of Palermo is mainly a passenger port, but which currently also hosts a significant traffic of containers for the Sicilian territory; it is also home to an important shipbuilding area managed by the Fincantieri company. In the recent regulatory plan of the port system, trade is foreseen to move to the port of Termini Imerese, in order to develop other areas in Palermo port for passenger and cruise transport. The port of Trapani is the primary maritime connections with the Egadi islands and Pantelleria, so it has a strong touristic vocation; historically, it is a reference port for trade with North African countries, and still maintains a trade route with Tunisia. The port of Porto Empedocle has historically been a hub for trade in salt and sulfur, and currently carries out mainly recreational activities.

The port of Messina is the first in Italy for passenger transport, with 10 million passengers per year before the pandemic. These figures are obviously due to the connection between Messina and the Calabrian ports of Villa San Giovanni and Reggio Calabria (also part of the Strait System Authority), which allow the connection of Sicily with the Italian peninsula. For these reasons Messina also records a high Ro-Ro traffic, but obviously to be considered only as in transit and not as origin or destination (which probably coincide with the cities of Catania or Palermo). As regards the port of Milazzo, there are two main types of traffic: passenger traffic connecting with the archipelago of the Aeolian Islands; freight traffic of liquid bulk, in particular hydrocarbons, due to a petroleum plant located in correspondence with the industrial port areas.

Table 1 shows the main freight statistics for the 2020 for all the ports of the case study.

**Table 1.** Statistics for the 2020 for the 8 ports (in tonns).

| Port | Solid bulk | Liquid bulk | Ro-Ro | Container | Total freight | Passengers (cruise + ferry) |
|---|---|---|---|---|---|---|
| Catania | 342.724 | 0 | 7.413.714 | 568.429 | 8.324.867 | 61.618 |
| Augusta | 1.042.452 | 22.987.553 | 0 | 0 | 24.030.005 | 0 |
| Palermo | 274.945 | 252.006 | 6.609.487 | 155.863 | 7.292.301 | 946.340 |
| Trapani | 33.234 | 0 | 82.699 | 144.749 | 260.682 | 816.624 |
| P. Empedocle | 323.242 | 0 | 25.902 | 0 | 349.144 | 40.113 |
| T. Imerese | 282.326 | 0 | 353.498 | 0 | 635.824 | 53.379 |
| Milazzo | 162.732 | 14.880.732 | 212.990 | 0 | 15.256.454 | 697.442 |
| Messina | 0 | 0 | 5.775.281 | 0 | 5.775.281 | 6.567.223 |

## 4.2 Data Acquisition

Data for port calls have been acquired manually from observations on an online provider of ship tracking services. Data have been collected for 2 weeks, from 23/07/2020 to 06/08/2020; the collected data were certainly influenced by the pandemic restrictions imposed by Italian government and for this reason it was decided to study only the port calls related to freight traffic. It was decided to exclude the traffic of liquid bulk from the analysis because the figures in the port of Augusta were not comparable to the ones in the other ports. Furthermore, the AIS did not record any port calls of exclusive freight traffic vessels in the selected period for the port of Messina (but mostly Ro-Pax), so this port was excluded from the analysis. Finally, after all the simplification, 7 ports and 3 traffic categories were taken into account.

All the port calls in which the Sicilian ports covered by the case study corresponded to an origin or a destination were taken into consideration. The entire route of each port call was included in the network, starting from the port of origin, and including also the intermediate stops.

### 4.3 Results

Figure 4 shows the whole network of connections of the Sicilian ports in GIS, exported from Gephi to.kmz format. The figure shows that the network includes (as well as several of the major Italian Thyrrenic ports) seaports located in Slovenia, Croatia, Montenegro, Albania, Greece, Malta, Turkey and North Africa, showing the relation between Sicilian Ports and the south and east of Mediterranean Sea. It is worth of notice that, even if it was not part of the case study, the Sicilian port of Pozzallo town is part of the network, mainly due to its role of intermediary connection with Maltese ports.


**Fig. 4.** Sicilian ports network in GIS after Gephi export.

Indexes have been evaluated for the global traffic and for 3 different traffic categories: Solid Bulk, Ro-Ro and Container. Table 2 shows results for all the traffic categories for the selected ports. Catania has the main centrality indexes when considering all the traffic categories. Augusta however has the main role of "stopping" port, with the highest betweenness for the selected period.

Table 3 shows results for the single traffic categories for each port. It must be highlighted that some calls were labelled as "General Cargo"; we decided not to use them in this representation, since it was not possible to trace back to the real traffic category (such vessels are often for mixed-use). Catania maintains its leadership also in the case of Ro-Ro traffic, showing also the highest amount of this traffic category in 2020. A different situation was recorded in the case of Container, where Trapani shows best centrality indexes, including betweenness. Augusta can be considered the only infrastructure with meaningful connections in the case of solid bulk.

**Table 2.** Global centrality indexes.

| Port | Degree | In degree | Out degree | Eccentricity | Closeness | Betweenness |
|---|---|---|---|---|---|---|
| Catania | 16.0 | 9.0 | 7.0 | 5.0 | 0.4 | 176.4 |
| Augusta | 13.0 | 8.0 | 5.0 | 5.0 | 0.4 | 202.8 |
| Palermo | 9.0 | 4.0 | 5.0 | 6.0 | 0.4 | 36.9 |
| Trapani | 6.0 | 4.0 | 2.0 | 5.0 | 0.4 | 72.0 |
| Porto Empedocle | 4.0 | 2.0 | 2.0 | 2.0 | 0.7 | 2.0 |
| Milazzo | 3.0 | 2.0 | 1.0 | 1.0 | 1.0 | 26.0 |
| Termini Imerese | 3.0 | 1.0 | 2.0 | 7.0 | 0.3 | 24.0 |

**Table 3.** Centrality indexes for differentiated traffic categories.

| | Port | Degree | In degree | Out degree | Eccentricity | Closeness | Betweenness |
|---|---|---|---|---|---|---|---|
| Solid bulk | Augusta | 6 | 4 | 2 | 1 | 1 | 8 |
| | P. Empedocle | 3 | 2 | 1 | 0 | 0 | 0 |
| Container | Trapani | 5 | 3 | 2 | 3 | 0.4 | 81 |
| | Catania | 4 | 3 | 1 | 9 | 0.2 | 34 |
| | Palermo | 2 | 1 | 1 | 6 | 0.2 | 49 |
| | T. Imerese | 2 | 1 | 1 | 1 | 1 | 0 |
| Ro-Ro | Catania | 11 | 6 | 5 | 2 | 0.7 | 27.2 |
| | Palermo | 6 | 3 | 3 | 3 | 0.5 | 1.7 |

### 4.4 Discussion: Policy Implications and Limitations

The analysis conducted, including the reasons for the exclusion of some traffic and ports, leads to the following considerations on the potential roles of Sicilian ports within their regional network:

– High degree centrality indices often correspond to high directness and coverage of the port in the network;
– There is a clear differentiation in the types of traffic handled in the port terminals which leads to a clear distinction of the indices for each traffic category;
– The Port System Authority of the Eastern Sicilian Sea could concentrate its activities on Ro-Ro traffic; in particular, in the search for synergy between the two ports, and given the available spaces, a share of the Ro-Ro traffic could be directed to the port of Augusta.

– The Port System Authority of the Western Sicilian Sea could concentrate its activities on increasing container traffic, in particular in the port of Trapani and taking advantage of the spaces available in the port of Termini Imerese.
– Ports of the System Authority of the Strait would keep their transit vocation to connect Sicily to the Italian peninsula
– The future of the industrial ports of Augusta and Milazzo must certainly be one of the key points in the planning of the respective port system authorities: the oil resources underlying their main activities will sooner or later run out and the recovery of the related port basins on which disused plants will gravitate.

Obviously, the results of these analyzes and related considerations suffer from some limitations of this study. First of all, the AIS data collected refer to the year 2020, with the beginning of the COVID-19 emergency: even if the reference period is one of the least impacted by the pandemic, one should consider that future trends will probably be significantly different from the traditional ones for maritime freight traffic. Furthermore, this analysis is restricted from a geographical point of view to the Sicily region, while the role of Sicilian ports is indisputably influenced by the surrounding ports; therefore, an analysis of the broader dynamics of the Mediterranean will be necessary in the future.

## 5 Conclusion

The purpose of the study is the characterization of the centrality of ports through the analysis of port calls automatically registered by AIS. Data acquisition using this innovative technological tool proves to be faster and more detailed than the traditional acquisition of statistics from port authorities. The calculation of centrality indices allows to analyse the importance of a port not only on the basis of the handled traffic, but also on its positioning as a node in the maritime transport network. This can help decision makers in the characterization of the specializations of a given port and its potential synergies with other nodes within a port system. From the application of the methodology to the case study of Sicilian ports, clear patterns of specialization emerged for the various ports and their related systems. The results suggest policies to promote further specialization of the ports towards the synergy of infrastructure operations in the Sicilian territory. The case study of this work is related to a local context, but future research could extend the application to the analysis of a port's centrality in the global maritime transport network.

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