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A Port Accessibility Index for Mediterranean container terminals

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Abstract

Using the Mediterranean as an application case, this study defines a Port Accessibility Index (PAI) useful to measure the accessibility of Mediterranean container ports. Traditionally, accessibility is measured as the quality of maritime links that connect ports together, without considering the port's characteristics. Differently from previous studies, this paper also focuses on the internal accessibility of the port. In so doing, the PAI will combine the Liner Shipping Connectivity Index with other factors, such as, time at port of container ships, maximum quay depth and number of containers per quay crane (QC) or per yard area. The application considers the 34 main Mediterranean container ports in terms of TEUs handled in the last decade. The results can contribute to highlight and identify the potential elements that could improve the accessibility of Mediterranean container ports, providing decision-makers with a useful wealth of knowledge when carrying out management strategies. Future studies may concern the extension of the research to other geographical areas with the inclusion of additional indicators (e.g., road and/or rail accessibility).

Keywords: Mediterranean container terminals; port accessibility; port performance indicators; container terminal competitiveness.

1. Introduction

In transport planning, accessibility is often treated as a factor useful for analyzing the development of transport infrastructure networks. The application of the concept of accessibility to containerized transport can assume the role of a descriptive indicator of the phenomenon, useful for investigating the performance and competitiveness of container ports (Wang and Cullinane, 2008). The accessibility of container ports reflects their potentiality in relation to the possibilities of being used among the worldwide containerized cargo trades. Therefore, accessibility is a key element in the analysis of the global containerized transport system. It is also a relevant aspect of port competitiveness as the throughput level in any container port is significantly correlated with its accessibility (Cullinane and Khanna, 1999; Wang and Cullinane, 2006). Nevertheless, even if throughput's growth is considered as evidence of port performance, this indicator gives only a partial view of the phenomenon (De Langen and Sharypova, 2013).

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Traditionally, accessibility is only used to measure the possibility of reaching a node in the network, using existing connections. This study will consider both external and internal accessibility. Maritime connectivity is one of the parameters generally used to evaluate port accessibility. It can be defined as an indicator of how well a port connects to other ports in a maritime network. A high level of connectivity ensures maximum maritime traffic and creates dynamism in the port and in the country's economy (Laird et al., 2005). Each container port aims to reach a high level of maritime connectivity, which also depends on the choices of shipping companies (Jouili, 2019). As hubs of exchange between maritime and land transport modes, ports are a key element for the economy of countries bordering the sea (Tovar et al., 2015). The countries and the ports that overlook the Mediterranean basin are a clear and evident example of this. In fact, the importance of container ports is even greater in this area (Fancello et al., 2021), which is considered as an application case in this study. The global liner shipping navigation network can be schematized using a graph made up of links (the liner shipping services that provide the connections) and nodes (the container ports). The aim of this work is to define an index useful for assessing the seaside accessibility of the main container ports in the Mediterranean Sea. In this study, accessibility is understood in a new perspective where not only physical accessibility (traditional) is considered but also different characteristics of the system are combined. To this end, a Port Accessibility Index (PAI) is proposed, which takes into account:

- Role of the terminal in the supply chain (gateway or transshipment)
- Connectivity with the other container ports, measured through the Liner Shipping Connectivity Index (LSCI)
- Time at port of container ships
- (infra)structural characteristics, number of quay cranes, berth length, yard area
- Structural adequacy of the terminal in relation to naval gigantism (maximum quay depth)

The structure of the paper is as follows. After this introductory section, Section 2 presents a literature review of the main indexes used to measure port accessibility. Section 3 illustrates the case study while Section 4 describes the methodology and data used to formulate the Port Accessibility Index. The results of the analysis are provided and discussed in Section 5. Finally, Section 6 concludes the paper.

2. **Literature review**

In the last years, various attempts have been made to develop indexes that could characterize container ports. Literature is rich of different indexes relating to competitiveness, accessibility, and connectivity of container ports. For example, Wang and Cullinane (2008) analyzed the world's top 10 container ports between 2003 and 2005 and measured two sorts of accessibility: topological accessibility that simply reflects the degree of connectivity between locations, and economic accessibility, computed by weighting the linkages between ports to reflect the opportunities for cargo movement. Tovar et al. (2014) developed a port accessibility index using the Canary Islands as an application case. Bartholdi et al. (2016) proposed a new index, the Container Port Connectivity Index, based on both economics and network topology, useful to measure the trade connectivity of ports within the container shipping network. Fugazza and Hoffmann (2017) investigated the relationship between bilateral maritime liner shipping connectivity and exports in containerized goods. Jouili (2019) studied the correlation between different variables, such as the liner shipping connectivity, the logistics performance, the container transit times, the container transport costs, the gross domestic product, and the container per capita. However, most of the proposed indexes consider only the inborn accessibility of the network links, but do not survey the internal accessibility of the nodes (i.e., the container ports). Actually, the characteristics of the single port are not evaluated. The level of connectivity between ports is often the only significant variable. Moreover, the role of the terminal (gateway or transshipment) is rarely taken into account. To overcome this critical issue, in this study the analyzed ports are divided into two different groups: gateway ports and transshipment ones. Among the others, the Liner Shipping Connectivity Index (LSCI), developed by UNCTAD, is one of the most common indexes used for analyzing the level of container port connectivity inside the global trade network. Nevertheless, it considers accessibility from the traditional point of view, that is, as a measure of the quality of the maritime links that connect ports together. Nothing is said about the internal accessibility of the port. Therefore, the authors have decided to consider the LSCI only as an external accessibility index, namely "network accessibility". In order to take into account the internal accessibility of the port, the authors will combine the LSCI with other factors, such as, time at port of container ships, maximum quay depth and number of containers (expressed in TEUs) per quay crane (QC) or per yard area. These factors are described in detail in Section 4.

3. **Case study**

This study uses as application case the Mediterranean basin. It considers the 34 main Mediterranean container ports in terms of TEUs handled in the last decade (see Figure 1 and Table 1).

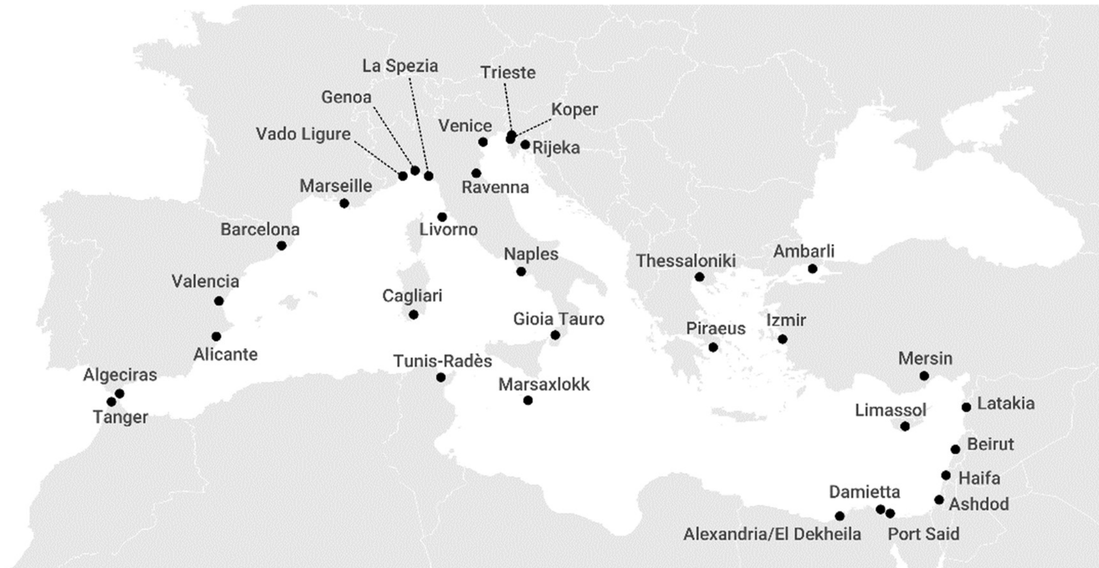

Fig. 1: Map of the 34 main container ports in the Mediterranean region

According to their main function, these ports can be divided into transshipment and gateway ports. The former dedicate most of their handling activity on transferring containers between ships. Transshipment ports take advantage of their favorable geographical position that allows them to intercept the great transoceanic routes, allowing the mother vessels to continue their journey to other continents or, by means of feeder ships, to reach the minor ports of the Mediterranean area.Gateway ports, on the other hand, are in strategic positions with respect to the large markets of origin or destination and play the role of doorways towards important economic areas. Gateway ports have gained a much better connectivity in the global shipping networks than before, which gives them the opportunity to benefit from a higher critical mass and economies linked to larger vessels (Gouvernal et al., 2005). In this scenario, transshipment ports are located along the Suez - Gibraltar route (e.g., Port Said, Piraeus, Marsaxlokk, Tanger and Algeciras), while Mediterranean gateway ports are mainly positioned along the Northern Mediterranean Range and the Eastern Mediterranean Range. Of the 34 ports considered, 12 are transshipment ports while the remaining 22 are gateway ones (see Table 1). Transshipment ports annually handle, on average, 56% of the total TEU throughput.

Table 1: List of the examined ports characterized by country, main service and traffic throughput (TEU, 2019).

Port	*Country*	*Main service*	*Port*	*Country*	*Main service*
Alexandria	Egypt	transshipment	Limassol	Cyprus	transshipment
El Dekheila	Egypt	transshipment	Livorno	Italy	gateway
Algeciras	Spain	transshipment	Marsaxlokk	Malta	transshipment
Alicante	Spain	gateway	Marseille	France	gateway
Ambarli	Turkey	gateway	Mersin	Turkey	gateway
Ashdod	Israel	gateway	Naples	Italy	gateway
Barcelona	Spain	gateway	Piraeus	Greece	transshipment
Beirut	Lebanon	gateway	Port Said	Egypt	transshipment
Cagliari	Italy	transshipment	Ravenna	Italy	gateway
Damietta	Egypt	transshipment	Rijeka	Croatia	gateway
Genoa	Italy	gateway	Tanger	Morocco	transshipment
Gioia Tauro	Italy	transshipment	Thessaloniki	Greece	gateway
Haifa	Israel	gateway	Trieste	Italy	gateway
Izmir	Turkey	gateway	Tunis-Radès	Tunisia	gateway
Koper	Slovenia	gateway	Vado Ligure	Italy	gateway
La Spezia	Italy	gateway	Valencia	Spain	transshipment
Latakia	Syria	gateway	Venice	Italy	gateway

4. **Methodology and Data**

Given a set of ports composed by m ports, and a set of variables a_j composed by n variables, equation (1) shows the generalized Port Accessibility Index (PAI) formulation for a port *i*. For each of the *n* variables a_j, the corresponding *i-th* port's value is divided by the maximum value the variable a_j reaches in the sample ($a_{j,i}/a_{j,max}$). Then, the mean of the *n* ratios is multiplied by 100, so as to generate the value 100 for the *i-th* port with the highest average index of the $_n$ variables.

$$PAI_i = \sum_{j=1}^{n} \left(\frac{a_{j,i}}{a_{j,max}}\right) \cdot \frac{100}{n} \quad (1)$$

$$\forall_j = 1, \dots, n \quad (2)$$

$$\forall_i = 1, \dots, m \quad (3)$$

Where:
$a_{j,i}$ = value assumed by the variable aj for the port *i*
$a_{j,max}$ = max value assumed by the variable aj in the sample

Specifically, the PAI formulation applied in this paper takes into account the following five variables (equation 4):

- LSCI: Linear Shipping Connectivity Index (proposed by UNCTAD) [dimensionless]
- τ: 1/Time at port of container ships [days-1]
- TEU/QC: TEUs handled per quay crane [TEU/QC]
- TEU/Yard: TEUs handled per yard unit [TEU/ m2]
- Max QD: Maximum quay depth [m]

$$PAI_i = \left\{\frac{LSCI_i}{LSCI_{max}} + \frac{\tau_i}{\tau_{max}} + \frac{(TEU/QC)_i}{(\frac{TEU}{QC})_{max}} + \frac{(\frac{TEU}{Yard})_i}{(\frac{TEU}{Yard})_{max}} + \frac{Max\ QD_i}{Max\ QD_{max}}\right\} \cdot \frac{100}{5} \qquad (4)$$

Each variable will be described in more detail in the following paragraphs.

4.1 The Liner Shipping Connectivity Index

The Liner Shipping Connectivity Index (LSCI) was developed by UNCTAD in 2004 to capture the level of integration of a country or a port into the existing global liner-shipping network. UNCTAD and MDS Transmodal jointly produce the current version of the index, which is published quarterly for each country and each port. At the country or the port that received the highest score in the reference year 2006 is assigned a value of 100, which serves as a benchmark to assign value to other ports and countries. The LSCI is based on regular container shipping services. It can be considered as a proxy for accessibility to global trade through the level of connectivity to the maritime shipping network (UNCTAD, 2019). The index is generated from six major components. Each component is considered as a possible indicator of the connectivity of a country:

1. Average size of the largest ship that is deployed to provide services from/to a port (TEUs): this is an indicator of economies of scale and infrastructure. Ports need to provide adequate equipment, such as ship-to-shore gantry cranes, and dredge their access channels to allow large containerships to be deployed.
2. Number of shipping companies that provide services from/to a country's ports (n. of companies): this indicator relates to how many shipping companies are servicing the country or the port.
3. Number of ports that are directly connected to the reference port (n. of ports).
4. Number of liner scheduled services that connect the reference port to other ports (n. of liner services): this indicator relates to how many scheduled services companies are using to provide total coverage.
5. Number of weekly scheduled ship calls that are deployed on services from/to a port (n. of weekly calls): this indicator concerns the number of ships that are calling on a weekly basis.
6. Total deployed container carrying capacity of the ship that provide services from/to my countries' ports (TEUs): it is the result of the number of port calls

multiplied with the average vessel size. The higher the capacity, the greater the potential to trade on global markets.

4.2 Time at port of container ships

Time at port, also known as port turnaround time, is the time frame since the ship reaches the port limits (pilot station or anchorage) until it departs from the berth after operations are completed. It includes waiting time, steaming-in time and berth time. The time taken to reach the port limits is not included. About 80 percent of the time in port spent by container ships is occupied by container operations that start when the first container is handled and finish with the last lifting. Longer port times do not always mean low efficiency. Ships can also extend their time in port to carry out some necessary operations before departure (e.g., refueling, purchasing services, repairing, or waiting in safe waters. Furthermore, longer times on average may occur due to the loading and unloading of high volumes. Clark et al. (2004) and Ng (2003) expressed that turnaround time directly affects port efficiency. Indeed, port efficiency and fast turnarounds are mutually related. Mokhtar and Shah (2006) found that vessel turnaround time is highly correlated with crane allocation as well as the number of containers loaded and discharged. It is also a function of port facilities and level of service provided at the terminal. Shorter turnaround time is beneficial to both the ports and port users (Dayananda et al., 2021). Long times at port are not always due entirely to problems in the port (e.g., lower STS crane efficiencies, labor issues, congestion in the terminal). Important differences between carriers exist too. Comtois and Slack (2019) concluded that carriers themselves are partly responsible for the variability among recorded time at port. Smith (2021) analyzed the container vessel call records for major U.S. ports between 2016 and 2018. He indicated a much stronger association of dwell time with expected cargo volume than with vessel capacity.

Time data used in this application was extrapolated from the database provided by MarineTraffic, based on the automatic identification system (AIS). The time at port does not consider the number of handled containers. Since time at port is inversely proportional to port's efficiency, the corresponding variable τ used in this study is constructed as an inverse function of the time spent in port. The shorter the time spent at port, the higher the value of τ.

4.3 TEU/QC, TEU/Yard area and Maximum quay depth

Two factors are chosen to represent the terminal's operating level, namely, the ratio between the number of containers (TEUs) per quay crane (QC) or per yard unit (m2). Finally, the maximum quay depth was chosen as an indicator of the port's ability to accommodate the ultra large container vessels (ULCV), thus responding adequately to naval gigantism. These factors represent the infrastructural characteristics of the port. The authors, using different sources, such as, the container terminal's websites, collected the values for each port. In the event that several terminals were included within the same port, the number of TEUs, the number of quay cranes and the yard area have been added up while the maximum quay depth was identified among the different terminals.

4.4 Data set

Table 2 and Table 3 present the average characteristics of the five variables used to build up the Port Accessibility Index. The variables are detailed in terms of lowest value, greatest value, mean, median and standard deviation. If we compare the mean values of the gateway ports' variables with the transshipment ports ones, we can notice that, for the latter, all values are higher (except the time at port which is inversely proportional to port efficiency).

Table 2: Gateway ports variables.

	LSCI	*Time in port (days)*	*TEU/QC*	*TEU/Yard*	*Max QD*	*Throughput (TEU)*
Lowest value	3.46	0.69	7,791.71	0.15	9.50	54,542
Greatest value	58.14	9.04	138,500.00	5.33	18.00	3,324,651
Mean	28.34	1.41	83,131.03	2.22	14.65	1,100,207
Median	30.12	1.12	79,742.60	2.28	14.75	789,736
Std. Deviation	16.568	1.720	29,563.268	1.368	2.182	937,237.472

Table 3: Transshipment ports variables

	LSCI	*Time in port (days)*	*TEU/QC*	*TEU/Yard*	*Max QD*	*Throughput (TEU)*
Lowest value	2.75	0.61	21,629.29	0.38	13.00	151,405
Greatest value	67.32	1.89	189,611.11	5.58	19.50	5,650,000
Mean	42.00	1.19	110,964.31	2.77	16.42	2,794,703
Median	49.98	1.16	117,103.15	1.92	16.75	2,621,437
Std. Deviation	22.643	0.356	46,766.547	1.829	1.987	2,103,401.213

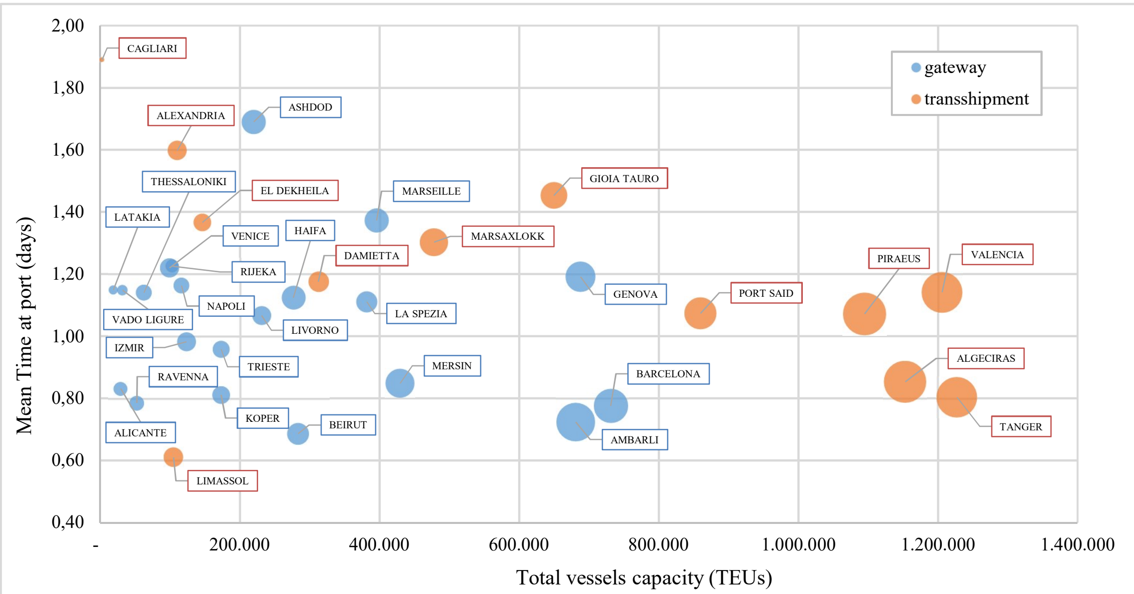

Fig. 2: Mean time in port, total vessel capacity and number of port calls per port (gateway, transshipment), container ships, Q1 2020

The plot in Figure 2 provides the relation between time in port and total vessels capacity at each port, distinguishing between gateway or transshipment ports. The x-axis shows the total vessels capacity during the first quarter (Q1) of 2020, while the y-axis the mean time in port (expressed in days) spent by container ships during the same period. The diameter of the bubble indicates the number of ship calls. The ratio between the total vessels' capacity and the number of ship calls provides the ship's mean capacity per port in the first quarter of 2020. Large ships with more cargo to be loaded or unloaded will normally require longer time in port, though ports that can handle larger ships also tend to be more modern and better equipped, meaning that they can work more quickly, therefore a non-linear relationship emerges (UNCTAD, 2021).

5. **Results**

Table 4 and Table 5 show, respectively for gateway and transshipment ports, the PAI value for each analyzed port, followed by the Linear Shipping Container Index and the TEU throughput in 2019. The PAI always obtains a higher score than the LSCI. However, they are not comparable. While the LSCI is based on the major world ports (e.g., the Asian ones), the PAI is related only to Mediterranean ports.

Table 4: Comparison between the PAI and the LSCI indexes for gateway ports

Port	*PAI*	*LSCI*	*Throughput 2019 (TEUs)*	*Port*	*PAI*	*LSCI*	*Throughput 2019 (TEUs)*
Alicante	46.10	5.24	170,739	Livorno	52.40	27.00	789,833
Ambarli	78.71	46.38	3,104,882	Marseille	46.89	9.36	1,454,621
Ashdod	63.74	35.71	1,400,000	Mersin	79.75	41.14	1,939,000
Barcelona	83.59	58.14	3,324,651	Naples	56.46	24.69	681,929
Beirut	76.98	44.07	1,229,081	Ravenna	42.28	9.60	218,138
Genoa	64.24	55.20	2,635,000	Rijeka	60.24	33.24	305,049
Haifa	65.97	39.99	1,400,000	Thessaloniki	53.67	13.48	448,766
Izmir	61.10	19.13	605,727	Trieste	66.75	33.67	789,640
Koper	82.42	35.57	959,000	Tunis-Radès	24.38	3.46	285,262
La Spezia	77.94	45.38	1,490,537	Vado Ligure	34.94	14.96	54,542
Latakia	38.51	8.57	325,097	Venice	47.93	19.48	593,070

Table 5: Comparison between the PAI and the LSCI indexes for transshipment ports

Port	*PAI*	*LSCI*	*Throughput 2019 (TEUs)*	*Port*	*PAI*	*LSCI*	*Throughput 2019 (TEUs)*
Alexandria	45.73	31.12	945,689	Limassol	54.21	18.59	389,900
Algeciras	92.39	67.32	5,119,500	Marsaxlokk	72.49	51.04	2,720,000
Cagliari	21.50	2.75	151,405	Piraeus	82.28	61.89	5,650,000
Damietta	54.19	35.12	1,068,002	Port Said	67.68	53.34	3,860,000
El Dekheila	37.92	7.59	869,261	Tanger	83.24	65.45	4,800,000
Gioia Tauro	58.62	48.91	2,522,874	Valencia	81.59	60.88	5,439,800

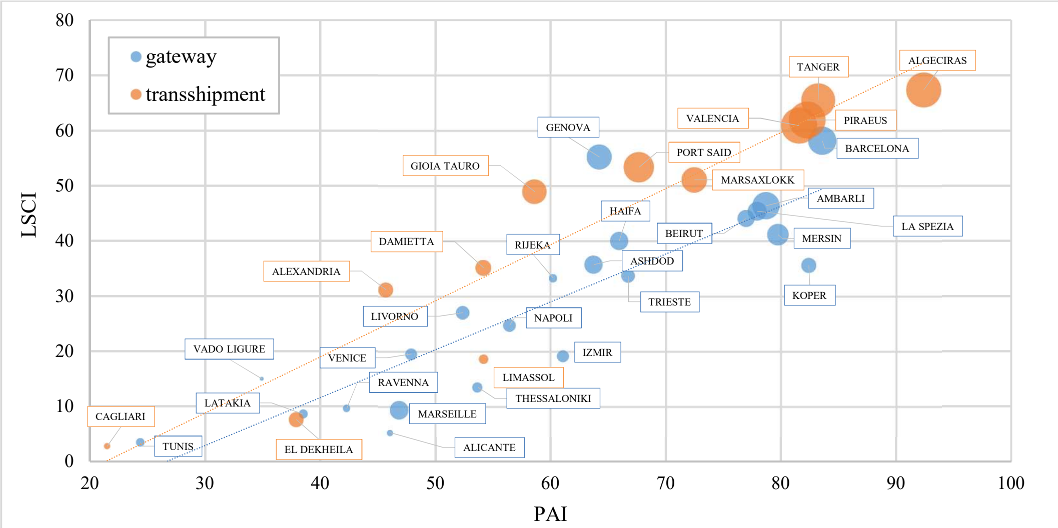

Fig. 3: Correlation between PAI and LSCI

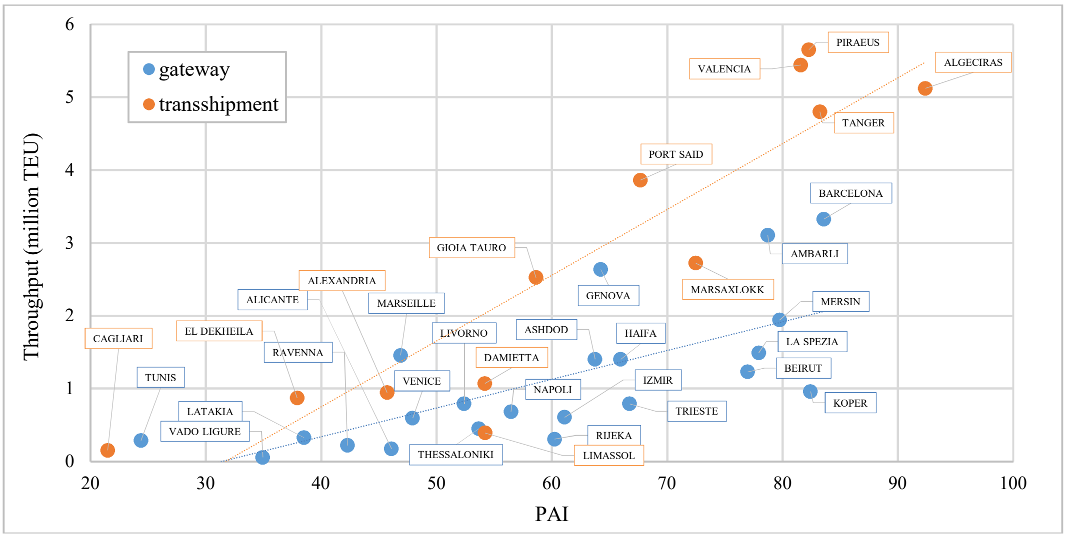

Fig. 4: Correlation between PAI and TEU throughput

Figure 3 provides the correlation between PAI and LSCI while Figure 4 the correlation between PAI and the TEU throughput in 2019. The figures show how the choice to calculate the PAI independently for the gateway and transshipment ports affects their positioning with respect to the LSCI (Figure 3) and to the TEU throughput (Figure 4). Furthermore, the ports of Genoa, Barcelona and Ambarli, despite been classified as gateway ports, occupy a position closer to transshipment ones. This is partly due to a significant percentage of transshipped containers.

6. **Conclusions**

This study proposed a Port Accessibility Index (PAI) to evaluate the accessibility of the main container ports in the Mediterranean region. Traditionally, port accessibility indices consider only the network accessibility, also known as external accessibility, that is, a measure of the quality of the maritime links that connect ports together. This new index introduces the concept of "node accessibility" that investigates the internal accessibility of the port. Therefore, the authors have decided to combine five variables that consider the different characteristics of the system. Compared with the Liner Shipping Connectivity Index proposed by UNCTAD, the Port Accessibility Index includes more information about the port's characteristics, including its main function, that is, gateway or transshipment. Indeed, as highlighted in the results Section, the role of the port in the supply chain affects its accessibility.

The results can contribute to highlight and identify the potential elements that could improve the accessibility of Mediterranean container ports, providing decision-makers with a useful tool when carrying out management strategies. It should be noted that the time at port in this application was only assessed for a short period of time (Q1, 2020). However, the application of big data in the form of AIS vessel call records could greatly improve the understanding of container vessel dwell times. Finally, in order to investigate the variations that occur during the years, future studies should quarterly update the index. Furthermore, future studies may also concern the extension of the research to other geographical areas with the inclusion of additional indicators (e.g., road and/or rail accessibility).

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