Analysis and Interpretation of Attributes Affecting Ship Time in Container Ports

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Abstract. The ship time in port is considered one of the most representative indicators of the performances of container ports and, more generally, of the countries' competitiveness in the international trade. The work presents the final results of a research project that aims to analyse and interpret the main attributes, or factors, affecting ship times in container ports and to establish correlations between the ship times and specific factors at the national and local (port) levels. The analysis and interpretation of the main attributes was conducted by calibrating descriptive models the put in relation the ship times with different categories of attributes related to the examined ships, ports, maritime services and the geographical areas. The results obtained could support the identification of the determinants that influence the competitiveness of container ports in order to identify and prioritize investments in port infrastructures.

Keywords: commercial ports · ship times in container ports · Transport System Models (TSMs) · attributes interpretation and evaluation · final results

1 Introduction

International trade has historically been based on the maritime transport of goods, which in turn depends on the structure of maritime routes and port systems. Among the most representative indicators of port performance is ship time in port, or ship turnaround time. This variable is one of the key indicators of the performances of container ports and, more generally, of the countries' competitiveness in the international trade [1].

In the above context, a research project titled: "National and local factors affecting times of ships in container ports", financed by the Italian Piano Nazionale di Ripresa e Resilienza (PNRR) inside the NextGenerationEU programme, was carried out by the Department of Information, Infrastructure and Sustainable Energy Engineering (DIIES) of Università Mediterranea di Reggio Calabria (Italy), as principal investigator, and the Department of Engineering of Università di Messina (Italy). The research project aims to identify the main attributes, or factors, affecting ship times in container ports and to establish correlations between the ship times and specific factors at the national and local (port) levels [2]. Ports are generally studied in the scientific literature as individual

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nodes, while there is no transversal and integrated knowledge about the set of ports of each country, although quantitative evaluations are necessary to support decisions about national investments in port infrastructures and policies. The existing research focuses mainly on single ports or terminals [3, 4], with a limited number of studies among different ports [5–7].

The methodologies adopted in the research project find their theoretical foundation in the framework of Transport System Models (TSMs) (see [8–14]). TSMs are conceived to simulate the behavior of both travelers and freight transport operators across multiple choice dimensions when interacting with transport infrastructures and services. TSMs consist of three main components: supply models, travel demand models, and assignment models. Supply models estimate the transport costs associated with the use of infrastructures and services. Supply models support the study the centrality that each port, or terminal, has in the structure of international maritime services [5, 15, 16]. Travel demand models estimate the choices of users based on the transport costs. The path choice models, in particular, estimate users' choices among available path alternatives [17–19]. Supply-demand interaction, or assignment, models calculate the flow and the (congested) costs on the elements of the network from the interaction between the multiple user's choices and the transport costs [11, 12, 20]. The literature about freight transport modelling concerns two levels: commodity-based and vehicle-based models, as reported in [21, 22] and [23].

The paper presents a three-level statistical analysis of the determinants of ship times in container ports, grounded on country-level macroeconomic, infrastructural and logistical indicators as well as port-level data. Statistical-descriptive models are employed to establish correlations between the average ship time in container ports, considered a dependent variable, with a set of attributes, as independent variables, defined at the national and port levels. The development of models is mainly based on the acquisition of data derived from Automatic Identification System (AIS) [24, 25]. As an example, Belcore and Polimeni [26, 27] introduced a modular framework to assess the phases of a ship call at port, allowing the identification of anchoring and berth operations, as well as the estimation of dwell time and waiting time. Such an approach also allowed to assess the performances of a port by means of a set of spatial-temporal indicators (spatial density, average service time, berth use) to investigate the operations performed in container ports [28].

Ship time in container ports may be considered an important indicator for assessing the competitiveness of countries and ports in the global supply chain, providing insights for the definition of intervention priorities and of appropriate measures to improve the performances of freight flow management in container ports and terminals. The results are important as they could support port authorities and planners to build national-level benchmarks among ports and to identify of each port's relative positioning.

The paper, after the introduction, is articulated as follows. Section 2 reports the specification of the model adopted. Section 3 presents the analysis and interpretation of the main attributes that are correlated with ship time in container ports at country and port levels. The last section is dedicated to the conclusions and the future research.

2 Models

The models used in the research belong to the class of statistical-descriptive, as they put in relation the average ship times in container ports, as dependent variable, with different attributes, as independent variables, at country and local levels [29–33]. The relationship is supposed to be one-way.

The general functional form of the model is:

$$t = t(\mathbf{x}; \boldsymbol{\beta}) + e \tag{1}$$

with:

t, ship time in port;
x, vector of attributes, or factors;
β, vector of parameters to be calibrated;
$t()$, function;
ε, error term.

By assuming that $t()$ is linear, Eq. (1) is specified as follows:

$$t = \beta_0 + \Sigma_j \beta_j x_j + \varepsilon \tag{2}$$

where:

x_j is the generic attribute;
β_0 and β_j are components of vector **β**.

The vector of parameters, **β**, may be calibrated by means of the Least Squares (LS) method, which allows to identify the vector $\boldsymbol{\beta}_{LS}$, among the different configurations of vector **β**, that minimizes the sum of the squares of the deviations between the observed values of ship times and the values of ship time calculated with Eq. (2).

The method has been applied both at country and port levels (see Fig. 1). At country level, the observed ship times, the estimated ones with Eq. (2) and the attributes are average values related to each country. At port level, the observed ship times and the estimated ones with Eq. (2) are AIS-derived related to each individual container ship, while the attributes are related to each ship and to the port.

3 Factors Affecting Ship Times in Container Ports

The research aimed to verify the correlation between the ship times of container ports and different attributes, of factors, at country and port levels.

At country-level, the analysis is focused on the performance of the container port system of a country as a whole, while at port-level the analysis concerned each container port.

The sources of data are different:

- country-level: the values of attributes are obtained from different data-base referred to the year 2019: UNCTADSTAT (www.unctadstat.unctad.org); The World Bank (www.worldbank.org); The Global Economy (www.theglobaleconomy.com);

- port-level: the attributes are built ad-hoc on the basis of the database provided by available AIS data [34] related to each individual ship extracted from the open-access platforms vesselfinder (vesselfinder.com) and ships.jobmarineman (ships.jobmarineman.com).

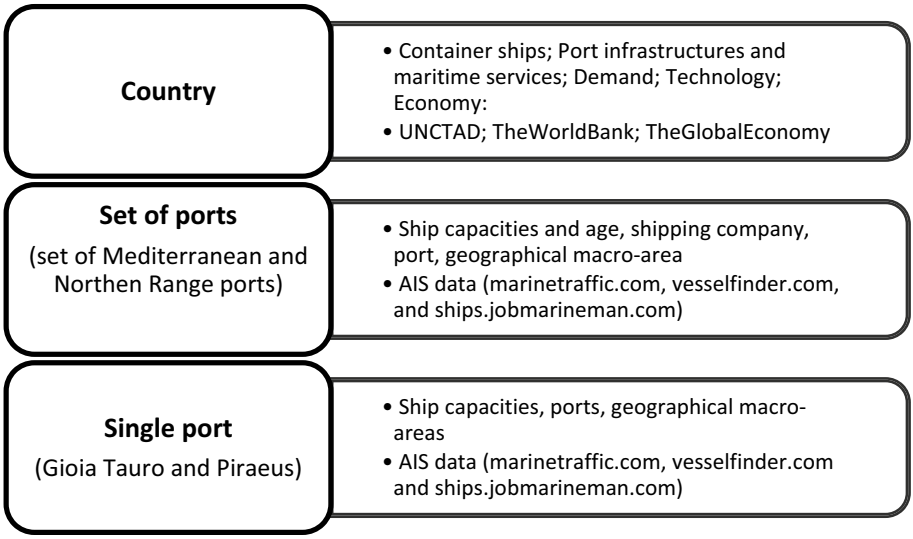

Fig. 1. Categories of attributes and sources of data at each level of analysis

3.1 Country Level

The experimentation at country level was conducted on a set of fifty countries belonging to Europe, Africa, Middle East and far East (see Fig. 2).

Definition of Attributes

The attributes considered in the analysis at country-level can be aggregated into different classes reported below.

The attributes related to the container ships are:

- the average gross tonnage of container ships, which indicates the average gross tonnage of container ships using country's ports during the period considered (year);
- the maximum gross tonnage of container ships, which indicates the maximum gross tonnage of the container ship that used at least one time one of the ports of the country during the period considered (year);
- the average capacity of container ships, which indicates the average capacity of by container ships using country's ports during the period considered (year).
- the maximum capacity of container ships, which is the maximum number of containers carried by a container ship using country's ports during the period considered (year).

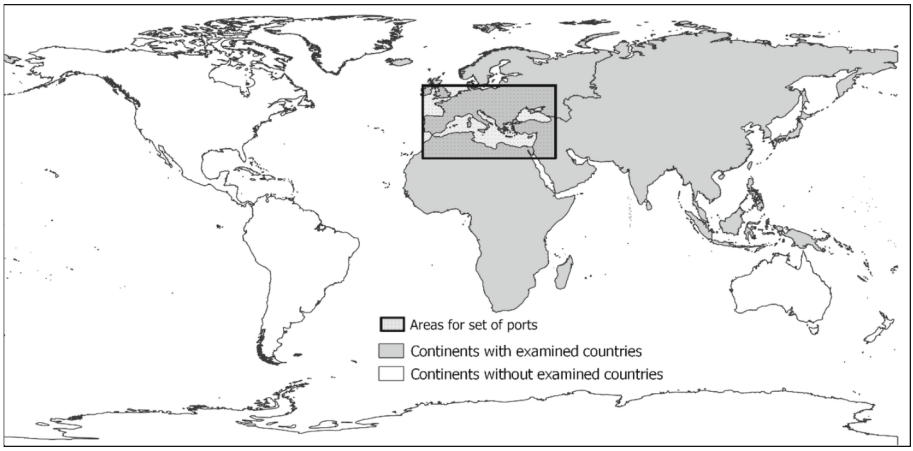

Fig. 2. Continents with examined countries.

The attributes related to the port infrastructures and maritime services are:

- the linear shipping connectivity index, which indicates the level of integration of a country inside the global maritime transport network;
- the logistics performance index, which indicates the efficiency of a country of handling goods both inside and outside the country;
- the port infrastructure index, which assesses the quality of a country's port infrastructure over a reference period (year);
- the number of ship calls, which indicates the number of port calls during the examined period by all ships (e.g. container ships) in all ports of the country.

The attribute related to the demand is the container throughput, which indicates the number of handled containers in a country during the period considered (year).

Two are the attributes connected to technology:

- the technology-overall index, which estimates technological capabilities of a country in relation to physical investment, human capital and technological effort and represents national capacities to use, adopt and adapt new-generation technologies;
- the ICT technology index, which estimates technological capabilities in a similar way to the technology-overall index, but only with respect to ICT technologies.

The attributes related to economy are:

- the gross domestic product, which indicates the average annual growth as a percentage of the country;
- the gross domestic product per capita, which indicates the average annual growth of gross domestic product per capita as a percentage.

Calibration Results

The correlation analysis shows that the ship time in port is highly correlated with the maximum capacity of container ships, the ICT technological index and the number of ship calls. The following general elements emerge:

- the ship time in port presents a declining trend and a reducing dispersion of values for increasing values of maximum capacity of container ships and of technological index;
- the ship time in port rapidly declines for increasing number of ship calls, until the threshold value of 5000 ship/year followed by a slight declining trend.

Several models have been calibrated considering different combinations of attributes belonging to the categories of attributes defined. Some comments concerning some attributes are reported below.

The models specified with the attribute maximum capacity of container ships generally present a negative value of parameter. This indicates that ship time in port reduces when the country is equipped with container ports able to handle ships with higher capacity; that is, countries having ports with larger physical infrastructures (e.g. docks, seabeds, …).

The models specified with the attribute number of ship calls also presents a negative value of parameter. The interpretation could be that an increase of the number of ship calls is associated with a better organization of the country's port system, leading to lower average ship times in port.

As for the two previous attributes, the models specified with the attribute ICT technological index present a negative value of the parameter. In other words, ship time in port reduces as the country's ICT dotation increases.

The ratio between the values of parameters associated with the attributes ICT technological index and maximum capacity of container ships attributes is 7.5. This means that an increase of +10% of the ICT technological index corresponds to an average increase of 750 [TEU] of the maximum capacity of container ships that can potentially be hosted in the ports of a country. Similarly, the ratio between the values of parameters associated with the attributes ICT technological index and number of ship calls is 450 on average. Therefore, an increase +10% of the ICT technological index corresponds to an increase of 450 [ships/year] ship calls in the ports of a country.

The models specified with the attributes linear shipping connectivity index, and logistics performance index, have both positive signs. They may indicate that container ports of countries with more connections and more logistics services are more congested; therefore, container ships spend more time in ports.

3.2 Set of Ports

The attributes of the model refer to a set of ports belonging to two macro-regions:

- Mediterranean Sea: Gioia Tauro, Piraeus, Livorno, Genoa, Valencia, Algeciras and Tanger Med;
- Northern Range: Rotterdam, Hamburg and Antwerp.

The following average values of ship times are calculated from the AIS-derived data in the set of examined ports. The average value of ship time in the port of Gioia Tauro is 34.0 h, while the average values in the ports of Algeciras and Tangier Med are respectively 21.2 h and 23.1 h. The port of Piraeus and Genova presents a value of ship time similar to the one of Gioia Tauro: 32.7 h in Piraeus and 35.0 h in Genova. The

average value is 28.3 h in the port of Rotterdam, while it is 53.1 h in the port of Hamburg and 46.4 h in the port of Antwerp.

Definition of Attributes

The attributes considered in the analysis at port-level can be aggregated into different classes reported below.

Ship:

- Age, [years], age of container ship calculated as difference between the current year and the year of building;
- Five specifications of ship capacity [TEUs] are considered:
  - Capacity1 $\in [0, +\infty]$
  - Capacity2 $\in [0, 12{,}000[$
  - Capacity3 $\in [12{,}000; +\infty]$
  - Capacity4 $\in [12{,}000; 18.000[$
  - Capacity5 $\in [18{,}000; +\infty]$

Shipping company (considering the alliances in year 2022):

- 2M $\in [0, 1]$
- Ocean Alliance $\in [0, 1]$
- The Alliance $\in [0, 1]$,
- Other $\in [0, 1]$

Port:

- Throughput
- PCS $\in [0, 1]$

Geographical macro-area to which the selected ports belong:

- Africa $\in [0, 1]$
- Southern Europe $\in [0, 1]$
- Northern Europe $\in [0, 1]$

Calibration Results

Among the models calibrated considering different combinations of attributes belonging to above categories, a selection of model results is reported below.

Some models have a positive value of calibrated parameter associated to the attribute Capacity1, which indicates that ship time in container port increases as the port is able to handle container ships with higher capacity. This result should be connected to the longer handling times due the higher number of unloading/loading operations of higher capacity container ships. The same consideration is valid for parameter of attribute, Age, which means that ship time in port decreases if the ship that arrives at the container port belongs to more recent generations. This could be due to the fact that ships built more recently have on-board equipment that allow more efficient operations.

A group of models has been specified with the attributes Capacity2 and Capacity3 in order to highlight possible non-linearity effects in the capacity attribute (2-class capacity). The calibrated parameters show that the ship time in ports increases as the ship

capacity increases, as for models specified with the attribute Capacity1. In particular, the ratio between the parameters associated to Capacity 2 and Capacity3 is 2/3; this means that container ships that have a capacity higher than 12,000 TEU has a greater impact on the ship times in port.

Another group of models is specified with the attributes associated to the ship capacity Capacity2, Capacity4 and Capacity5 with the same objective of the previous group of models (3-class capacity). It is worth noting that the value of parameter associated to the attribute Capacity4 is greater than the values of parameters associated the other two classes: Capacity2and Capacity5. This means that higher ship times in port are associated to the class of container ships with capacity between 12,000 and 18,000 TEUs. The lower value of parameter associated to attribute Capacity5 could be justified by the fact that the latest generation of ships (ULCS and New Panamax types) have priority over the ships with less capacity in the container ports considered.

Models specified with geographical attributes, as Southern Europe and Northern Europe, present positive calibrated parameters. This indicates that container ports of Southern Europe and Northern Europe have higher ship times than African ports (Tangier Med). The result is important because it establishes some reference thresholds of ship times in container ports belonging to the three examined geographical macro-areas.

3.3 Single Port: Gioia Tauro and Piraeus

The paragraph describes a further analysis at port-level concerning two ports: Gioia Tauro (Italy) and Piraeus (Greece). The container terminal of Gioia Tauro is managed by Terminal Investment Limited (TIL belonging to MSC Group). It is located along the Suez-Gibraltar route with deep sea-beds up to 18 m and 1.7 km of quays extension. TIL has recently renewed the fleet of vehicles inside the yard by switching from straddle carriers to transtainers, allowing containers to be stacked from two to three-four levels. As consequence, the port increased the handling and storing capacity and the container throughput passed to approximately 3.9 million of TEUs in 2024 and 4.5 million of TEUs in 2025. Container traffic by rail mode with Northern Italy and Central Europe is less developed than the large hub ports of Northern Europe. The gateway handled almost 1,000 trains/year in 2025. The large hinterland area has strong development potentials; but the initiatives of the regional Calabrian government of creating a location-based and sector-based special economic zone (Calabria Region 2016, 2018 [35, 36]) were modified by the Italian national government by creating a special economic zone for the entire South of Italy and covering the whole economic sectors (Musolino et al. 2023 [37]; Russo and Musolino, 2023 [38]). The container terminals of port of Piraeus are operated by the Piraeus Container Terminal company, under the control of COSCO Group. The container throughput oscillated between 4.0 and 5.0 million of TEUs in the last years. COSCO Group established in Piraeus its hub for routes and commercial strategies in the Mediterranean Sea. The port has no rail and road connections with Central Europe (Piraeus Port Authority, 2024 [39]; Galani, 2025 [40]).

Definition of Attributes

The following attributes are considered at this stage.

Ship:

- Age, [years];
- Five specifications of ship capacity [TEUs] are considered:

  – Capacity1 $\in [0, +\infty]$
  – Capacity2 $\in [0, 5{,}000[$
  – Capacity3 $\in [5{,}000; +\infty]$
  – Capacity4 $\in [5{,}000; 15{,}000[$
  – Capacity5 $\in [15{,}000; +\infty]$

Port:

- Reference Port $\in [0; 1]$, equal to 1 if the port is Gioia Tauro or Piraeus, 0 otherwise:
- Distance from Previous Port call $\in [0, +\infty]$, distance between the previous port of call and the reference port (Gioia Tauro or Piraeus);
- Distance from Next Port call $\in [0, +\infty]$, distance between the reference port (Gioia Tauro or Piraeus);
- Transhipment Previous Port $\in [0, 1]$, is equal to 1 if when the previous port called is a transhipment hub port, otherwise 0:
- Transhipment Next Port $\in [0, 1]$, is equal to 1 if when the next port called is a transhipment hub port, otherwise 0:

Geographical Area

- Previous Port call $\in [0, 1]$, it is equal to 1 if the previous port of call is located in one of the three geographical areas: Indo-Pacific, Mediterranean, North Sea; it is equal to 0 if the previous port of call is located in the geographical area of Atlantic;
- Next Port call $\in [0, 1]$, it is equal to 1 if the next port of call is located in one of the three geographical areas: Indo-Pacific, Mediterranean, North Sea; it is equal to 0 if the next port of call is located in the geographical area of Atlantic;
- Chain $\in [0, 1]$ is equal to 1 if the previous and next port call belong to the Mediterranean area, otherwise it is 0.

Parameters' Calibration

Several specifications of models have been calibrated. Some comments of the main results are reported below.

Preliminary, the parameter defines the reference threshold of ship port time for Gioia Tauro and Piraeus. The value of the calibrated parameter of the attribute Reference Port is 2.37 [hours], as expected, confirming the differences in the observed average values of ship times of the two ports.

Models specified with the attributes Capacity2 and Capacity4 show that ships with capacity lower than 5,000 TEU present an increasing ship time than the ships with capacity between 5,000 and 15,000 TEU. This result is in line with what happens in the transhipment hub container ports, like Gioia Tauro and Piraeus, where mother ships have priority in the port respect to feeder ships.

Models specified with attributes belonging to the category Geographical area show that ships arriving from ports belonging to the macro-area of the Indo-Pacific, the Mediterranean and the North Sea (or having a port as next destination belonging to

the macro-area of the Indo-Pacific, the Mediterranean or the North Sea), have a lower port time than Atlantic, assumed as reference area.

4 Conclusions

Container ports are complex systems, where three main categories of elements coexist and concur to their competitiveness:

a) physical infrastructures on the seaside, like breakwaters, quays, draught; and on the landside, like loading/unloading areas, last-mile connections with terrestrial networks; warehouses;
b) port governance and port organization, such as maritime services operated by shipping companies, handling and storage services operated by terminal companies;
c) immaterial infrastructures, such as emerging ICT, research and education.

The paper presents an analysis and interpretation of the main attributes, or factors, affecting ship time in container ports, which is considered one of the most representative indicators of the performances of container ports and, more generally, of the countries' competitiveness in the international trade.

The analysis has been conducted at country and port levels. The analysis and interpretation of the attributes is executed by calibrating descriptive models that put in relation the ship time in container ports with different categories of attributes related to the ships, the ports, the maritime services and the geographical areas examined.

The proposed three-level structure of analysis allows to obtain results ranging from the macro level, country, to the micro level, port. The finding that ICT investments and physical infrastructure investments may have equivalent marginal effects on ship time could be a result of practical significance for port planners. The selection of Gioia Tauro and Piraeus as a case study is motivated as these ports are considered to be major transhipment hub ports in the Mediterranean area.

The limitations are reported in the following. The temporal scope and the undiscussed sensitivity of the results regarding the identification of thresholds of the classes of container ship capacity constrain the generalisability and reproducibility of the findings. The data at the country level concern the year 2019, a pre pandemic period, which do not allow to discuss whether the identified relationships are expected to hold under the altered shipping conditions belonging to the post 2020 period, characterized by severe port congestion, supply chain disruptions, accelerated digital transformation, war in Ukraine.

Further developments concern the investigation about the influence of further attributes not considered in the models presented and the extension of the data-base by adding observations about new container ports and post-2020 years.

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