



# Attributes influencing port times of container ships

Francesco Russo<sup>1</sup> · Girolamo Pedà<sup>2</sup> · Giuseppe Musolino<sup>1</sup>

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## Abstract

Shipping of freight by sea is the pillar of international trade. Maritime transport has its crucial nodes in the port systems. One of the main characteristic of ports in the context of maritime transport, is given by the port time of ships from arrival to departure in/from the port, after having completed the loading/unloading operations. It is therefore necessary to know how the different attributes of the ports influence the port times of ships. The most important attributes are then discussed and a multiple linear regression model is estimated. The results obtained are interesting because they highlight the role of attributes that affect the entire port system, such as the ship capacity. The results are important because they make it possible to identify overall investments relating to the single port system in addition to the usual actions to optimize the processing of individual ships.

**Keywords** Third-generation port · Ship port time · Container ports · Transport system models · Aggregated calibration

## 1 Introduction

The main pillar of international trade is the maritime transport of freight, allowing the integration of countries of different continents, which took place in the first two decades of the twenty-first century. The globalization of national economies determined a shift to export-oriented policies based on maritime transport. The main elements of maritime transport are sea routes and port systems. The sea routes depend, on the one hand, on the types of ships available and, on the other, on the organization of services at a global scale that can be different in relation to the available ports' supply. As an example, the hub-and-spoke structure of sea routes can be implemented only if large ports capable of hosting the Round-The-World (RTW)

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✉ Giuseppe Musolino  
giuseppe.musolino@unirc.it

<sup>1</sup> DIIES – Dipartimento di Ingegneria dell'Informazione, delle Infrastrutture e dell'Energia Sostenibile, Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy

<sup>2</sup> Engineering Degree, Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy

container ships, operating along deep-sea routes, are available. The importance of the generic port as a hub of a system depends on its degree of centrality (Barthelemy 2015; Giuffrida et al. 2021a; Russo et al. 2023a).

In order to define the role that a single port plays in the international context, it is necessary to identify homogeneous categories of ports that operate with similar infrastructures and equipment and that allow the movement of ships that have homogeneous characteristics, associating each port with a category.

Numerous proposals have been made in the scientific and technical literature to classify ports. The complexity in establishing universally accepted classifications arises from the diverse nature of ports and port systems.

In 1994, UNCTAD introduced the concept of “generation” and outlined the characteristics of three generations of ports (UNCTAD 1994). This classification has been well accepted in international technical contexts, albeit with some differentiations. In extreme synthesis, the first generation includes the historic ports that have grown in synergy with the cities (Russo and Musolino 2012, 2023a; Bretagnolle 2015; Balletto et al. 2022), the second generation includes the industrial ports developed close to large energy and steel plants (Giuffrida et al. 2021b; Fattah et al. 2022; Russo and Musolino 2023b), the third generation belongs to the ports that manage large volumes of containers increasing the added value of freight (Panova and Hilletoft 2019; Russo and Musolino 2020). Third generation ports have two territorial distinctive characteristics (Russo and Chilà 2021a, b; Pellicanò and Trecozzi, 2022): the areas inside the port borders (Russo and Rindone 2021) and those of the port hinterland (Musolino and Chilà 2021a; Musolino et al. 2021b; Musolino and Trecozzi 2021c).

In later years, several proposals were made after the definition of fourth generation ports provided by UNCTAD (1999). Among the others, it is worth recalling the works of Paixao and Marlow (2003); Beresford et al. (2004); Bichou and Gray (2005); Flynn et al. (2011); Russo and Musolino (2021a); Rouboutsos et al. (2022). In general, the fourth generation ports have the characteristic of integrating multiple port infrastructures into a single management authority. Recently, some studies introduced the definition of fifth generation ports, which are equipped with fundamental technological integrators of port actors and functions (see Russo and Musolino 2021b; Musolino et al. 2022; Jović et al. 2022; and references included). The technical debate on these two classes is still ongoing (Szaruga et al. 2021; Chloumoudis et al. 2022; Othman et al. 2022; Deng et al. 2022).

It therefore emerges that the main factor influencing the performance of ports, on the sea side, is the overall time of the ship in the port. The overall time is generally computed from the arrival at anchor to the ship's entry into the port until its departure after completing the loading and unloading operations. The time spent by ships in port may be considered one of the relevant aggregate indicator of a port's performance.

An important study is the one conducted by the International Finance Corporation in 2013. The study highlighted relevant differences in export/import times between countries with similar technical-administrative structures and within the same economic-political regions. This discrepancy is particularly pronounced in Europe, where export times have an average value of ten days, but vary significantly from country to country compared to the average value. Starting from the results of the study of the International Financial Corporation (2013), the Italian Presidency of

the Council conducted an analysis of the times linked to good export. These times were classified into: documentation times; customs times; handling and transport times (Presidenza del Consiglio dei Ministri 2014). It is possible immediately to note that, while customs times remain relatively similar between different countries, documentation and handling times show notable disparities between the different countries. It is therefore necessary to study in an aggregate way which attributes, of national significance, contribute to these relevant differences.

The paper tries to respond to the two following Research Questions (RQ). The first RQ is: which are the main factors, or attributes, that affect port times of container ships? The second RQ is: is it possible to calibrate a function that put in relation the average ship times in container ports to ports attributes?

The reply to the first question implies a careful analysis of the existing available data at port level. An interesting class of data for this scope may be obtained from Automatic Identification System (AIS), that allow to track container ships entering and leaving a container port.

The reply to the second question implies the building of a state of the art on models describing the above relationship. Two different approaches are present in the literature: aggregated and disaggregated (Gattuso and Musolino 2001). The most common models for the estimation of generalized cost functions are statistical-descriptive; which estimate the attributes of cost by means of functional relationships with service level and economic-territorial attributes (Russo 2005).

The objective of the paper concerns the analysis and the evaluation of container ports' performances, according to quantitative indicators that link ports' attributes with the average port ship times. Specifically, the paper analyses and model the ship times of container ports because they are an important element for the port choices of shipping companies and because they directly affect economic transport costs of containers. It is worth noting that the documentation and customs times depend mainly on the administrative organization of the country and not directly on the ports' organization.

According to the above RQs, the paper is structured as follows. Section 4 provides a description of the main factors that affect ships' operations and times within the port. In particular, the section describes the method used to estimate the parameters of the attributes that influence the port time of container ships. Section 6 presents the results of a descriptive analysis of the available sample data and the results of the parameters' estimation of the specified models. Some conclusions and research developments are presented in the last section.

The analysis of factors that affect port times of container ships is useful for technicians and planners operating both at port and national level, because it allows to identify the critical elements in container port operations in order to improve port's competitiveness in the global market.

## 2 Attributes affecting ship times in container ports

The port ship time is the time spent by the ship in the port and it is calculated from the ship arrival in proximity of the port until the ship leaves the port after completing the loading / unloading operations. It is recognized that the container

port operations and performances (e.g. port ship times) are influenced by the port geographical position and function (e.g. hub port vs. feeder port) in the international supply-chains, and the consequent organization of the maritime services; by the efficiency of the administrative system of the country/region that hosts the port (e.g. documentation, custom and checks, ...); by the port dotation of material infrastructures (e.g. quays and docks, maximum draught, hinterland connections) and immaterial infrastructures (e.g. presence of Port Community Systems-PCS, level of usage of emerging ICT – internet of thing, big-data, block-chain, digital twin). Gattuso and Musolino (2001) describe the port ship time as a variable dependent on numerous factors: some of them are linked to operational activities, others have an economic-political nature. According to Reya and Strachan (2021), ships can spend additional time in port, associated with activities such as repairs or because they are unable to moor in the next port of destination; this extra time is generally excluded from the calculation of port ship time. No systematic studies are present in the literature highlighting the relationships between the ship times in the port and the above attributes. The existing study of ship times at ports generally focus on a single port or terminal, with rare comparative studies. It is worth to recall the following recent studies that analyse port ship times at country level (Russo et al. 2022; Ducruet and Itoh 2015, 2022; Mazibuko et al. 2024).

The methods and models used in this study have their theoretical background in Transport Systems Models (TSMs) framework (Cascetta et al. 1996; Cantarella 2008; Cascetta 2009; Ben-Akiva et al., 2019; Tavasszy and de Jong 2014; and references included). TSMs simulate a transport system through a process, in which transport supply and travel demand interact. The three main elements of the TSM are: the transport supply model, the travel demand model and the supply-demand interaction model. The transport supply model quantifies the utilities of users deriving from the use of transport infrastructures and services. The approach used is the topological model, given by a network model. The travel demand model simulates the users' choices based on the performance of infrastructure and services. Travel demand models can be behavioural or non-behavioural. The supply-demand interaction model allows simulating the interaction between the users' choices and the performance of the infrastructure and the service. The model uses the topological-behavioural paradigm.

As far as concerns the supply model, the port operations, and the related times, may be analyzed and schematized by means of disaggregated or aggregated approaches. Disaggregated approach relies on network models, with links, nodes, and cost functions (e.g. time-flow relationship). Network models may be classified in: synchronic, or static, models and diachronic, or dynamic, models (Russo 2005; Cascetta 2009). Aggregate approach estimates an aggregate supply characteristic (e.g. the port ship time), as the effect of the disaggregate infrastructural, technological and operational dimensions within container ports.

As far as concerns the demand models, two different modelling approaches have been proposed in the literature: aggregate and disaggregate (Russo 2005; de Jong et al. 2013). Aggregate models are more commonly used due to the relative availability of traffic data for models' calibration and validation purposes. In several cases,

they follow the partial-share approach similarly to the passenger travel demand models. Disaggregated models present greater complexity due to the difficulty of obtaining data about companies' strategies, which operate in a highly competitive market. Many models simulate the transport choices of companies that need to ship freight by establishing the frequency and size of shipments according to the prices offered, to the reliability and to attributes of the shippers.

Freight demand models can be also sub-divided into three classes:

- statistical-descriptive models; which estimate maritime demand flows by means of functional relationships with level of service and economic-territorial attributes (Meersman and Van der Voorde, 2008; Meersman et al. 2009), or by the means of the minimization of transport costs and/or logistic cost functions; statistical-descriptive models; which estimate maritime demand flows by means of functional relationships with level of service and economic-territorial attributes (Meersman and Van der Voorde, 2008; Meersman et al. 2009), or by the means of the minimization of transport costs and/or logistic cost functions;
- time series models; that use historical data to forecast maritime demand flows between production/consumption regions;
- partial-share models, which use the typical structure of passenger demand models (multi-step structure) to the case of freight transport: generation/attraction, distribution, service, port, and (maritime) line.

The supply models used in this study belong to the aggregated approach, which put in relation the average port time of container ships, as dependent variable, with different attributes at port level, as independent variables. The relationship is supposed to be one-way cause-and-effect, that is, independent variables affect the dependent variable.

The motivation of using aggregated models rely to the objective of the research, which concerns a spatial analysis of time of ships across container ports of the world. The development of a network model in each port for the objective of comparison would be a so hard issue, in terms of data acquisition necessary to calibrate the disaggregate cost functions related to the individual operations inside each port.

The next paragraphs present the basic formulation of the method and, then, the attributes used for the model specification.

## 2.1 Method

The general functional form of the model is the following:

$$y = f(\mathbf{x}; \boldsymbol{\gamma}) + \varepsilon \quad (1)$$

where.

$\mathbf{x}$  is the vector of independent variables (or attributes);

$y$  is the dependent variable;

$\boldsymbol{\gamma}$  is a vector of unknown parameters;

$f()$  is a function;

$\varepsilon$  is the error term.

By assuming a linear specification for  $f()$ , Eq. (1) may be specified as follow:

$$t_{pi} = \gamma_0 + \sum_j \gamma_j x_{ji} + \varepsilon_i \quad (2)$$

where.

$t_{pi}$ , estimated ship time in port  $i$  [h];

$\gamma_0$  and  $\gamma_j$  are components of vector  $\boldsymbol{\gamma}$ ;

$x_{ji}$  is the attribute  $j$  related to port  $i$ , component of vector  $\mathbf{x}$ .

The model of Eq. (2) is called multiple linear model. The vector of parameters,  $\boldsymbol{\gamma}$ , is calibrated by means of the Least Squares (LS) method. LS operates by identifying the vector  $\boldsymbol{\gamma}_{LS}$ , among the configurations of vector  $\boldsymbol{\gamma}$ , that minimizes the sum of the squares of the deviations between the observed values of ship times in port (independent variable) and the values of ship times in port estimated by model of Eq. (2):

$$\boldsymbol{\gamma}_{LS} = \min \sum_{i \in I} \left( t_{pi,obs} - \left( \gamma_0 + \sum \gamma_j x_{ji,obs} \right) \right)^2 \quad (3)$$

with:

$i$ , value related to port  $i$ ;

$I$ , set of observed ports;

$\boldsymbol{\gamma}_{LS}$ , vector of parameters that minimizes Eq. (3);

$t_{pi,obs}$ , observed ship time in port  $i$ ;

$x_{ji,obs}$ , observed attribute  $j$  related to port  $i$ .

The validation of models is executed by means of two following indices.

The first is the multiple correlation index, denoted with  $R^2$ , which measures the intensity of the linear relationship between the dependent variable,  $y$ , and the vector of attributes,  $\mathbf{x}$ . The  $R^2$  index is equal to:

where:

$RSS = \sum_{i \in I} (t_{pi,obs} - (\gamma_0 + \sum \gamma_j x_{ji,obs}))^2$ , is the residual deviance;

$TSS = \sum_{i \in I} (t_{pi,obs} - t_p)^2$ , is the total deviance;

$t_p$  is the average value of the observed ship time in port.

The second is the adjusted multiple correlation coefficient, denoted by  $R^2$ , that consider the number of parameters used in the estimated model:

$$\underline{R}^2 = 1 - (n - 1) / (n - k - 1) RSS/TSS$$

where:

$n$  is the number of observations belonging to  $I$ ;

$k$  is the number of attributes considered.

## 2.2 Attributes

The model supports the identification and quantification of the determinants of ship times in container ports based on various attributes, belonging to disaggregate infrastructural, technological and operational dimensions of the generic container port.

The model specification considers four classes of attributes, defined below:

- ‘Ship’, attributes of container ships using to the port,
- ‘Port’, attributes that relate the demand to the physical and digital infrastructures,
- ‘Shipping company’, attributes related to the company, or the alliance, using the container ship arriving at the port; it is worth noting that there is a strong cooperation between shipping companies, in the form of alliances, that arises from the necessity to share risks, costs and investments connected to the creation and maintenance of a network of maritime services,
- ‘Geographical macro-area’, attributes related to the geographical macro-area to which the port belong.

The attributes belonging to class ‘Ship’ are defined as follows.

- Age, [years], age of container ship calculated as difference between the year 2022 and the year of building;
- Capacity, Cap, [Twenty-Equivalent-Units, TEUs/10<sup>3</sup>], maximum number of containers loadable by the container ship.

The capacity attribute has been specified in different ways.

1) Capacity, Cap  $\in [0; + \infty]$

2a) capacity > 12,000 TEUs, Cap > 12, [TEUs/10<sup>3</sup>], is defined as follows

$$\text{Cap} > 12 = \begin{cases} \text{Cap} & \text{if } \text{Cap} \geq 12,000 \text{ TEUs} \\ 0 & \text{if } \text{Cap} < 12,000 \text{ TEUs} \end{cases}$$

2b) Capacity < 12,000 TEUs, Cap < 12, [TEUs/10<sup>3</sup>], defined as follows:

$$\text{Cap} < 12 = \begin{cases} \text{Cap} & \text{if } \text{Cap} \leq 12,000 \text{ TEUs} \\ 0 & \text{if } \text{Cap} > 12,000 \text{ TEUs} \end{cases}$$

The attributes 2a and 2b are jointly used in the same model and allow to capture the presence of different elasticities of port ship time to the ship capacity in correspondence of a threshold value Cap = 12,000 TEUs.

3a) Capacity > 18,000 TEUs, Cap > 18, [TEUs/10<sup>3</sup>], is defined as follows:

$$\text{Cap} > 18 = \begin{cases} \text{Cap} & \text{if } \text{Cap} \geq 18,000 \text{ TEUs} \\ 0 & \text{if } \text{Cap} < 18,000 \text{ TEUs} \end{cases}$$

3b) 18,000 > Capacity > 12,000 TEUs, 18 > Cap > 12, [TEUs/10<sup>3</sup>], is defined as follows:

$$18 > Cap > 12 = \begin{cases} \text{Cap if } 18,000 \geq Cap > 12,000 \text{ TEUs} \\ 0 \text{ if } Cap > 18,000 \text{ TEUs \& } Cap < 12,000 \text{ TEUs} \end{cases}$$

3c) Capacity < 12,000 TEUs, Cap < 12, [TEUs/10<sup>3</sup>], is defined as follows:

$$Cap < 12 = \begin{cases} \text{Cap if } Cap \leq 12,000 \text{ TEUs} \\ 0 \text{ if } Cap > 12,000 \text{ TEUs} \end{cases}$$

The three above attributes 3a, 3b and 3c are jointly used in the same model and allow to catch the presence of different elasticities of port ship time to the ship capacity in correspondence of the two threshold values: Cap = 12,000 TEUs and Cap = 18,000 TEUs.

The attribute belonging to the class 'Port' is related to the presence and the level of development of the Port Community System (PCS) in the port:

- PCS [0, 1], is equal to 1 if the port is equipped with a PCS, and 0, if not.

The attributes belonging to class 'Shipping company' are the following.

- 2 M [0, 1], is equal to 1 if the container ship belongs to 2 M alliance, and 0 if not.
- Ocean Alliance (OA), [0, 1] is equal to 1 if the container ship belongs to Ocean Alliance, and 0 if not.
- The Alliance (TA) [0, 1], is equal to 1 if the container ship belongs to The Alliance, and 0 if not.
- Other (OT) [0, 1] is equal to 1 if the container ship does not belong to any alliance, and 0 if not. The attribute includes all container ships that does not belong to any company participating to the previous alliances.

The attributes belonging to class 'Geographical macro-area' are the following.

- Africa (AF) [0, 1] is equal to 1 if the port is an African port, and 0 if not.
- South Europe (SE) [0, 1] is equal to 1 if the port belongs to a Southern Europe country (Mediterranean country), and 0 if not.
- Northern Europe (NE) [0, 1] is equal to 1 if the port belongs to a Northern Europe country; and 0 if not.

### 3 Results

According to the multiple linear regression model previously described and of the attributes selected and investigated, this section presents the estimation of the model parameters. A descriptive analysis of the observed values was first carried out. The indications that emerged allow to identify the basic models to be calibrated.

### 3.1 Descriptive analysis

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 attributes ‘age’ belonging to the class of ‘Ship’ and the ‘Shipping company’ attributes were extracted from Automatic Identification System (AIS) data on vesselfinder.com, while the attributes of ‘capacity’ of container ships were extracted from ships.jobmarineman (ships.jobmarineman.com). The values of the attribute related to the presence and the level of development of a PCS in the port, on the other hand, were obtained from the scientific literature.

Table 1 shows some descriptive statistics about the database built using AIS data, extracted from the web (vesselfinder.com): the maximum, average, minimum and coefficient of variation values of ship times in container ports, and of the capacity of container ships. As far as concerns the ship times in container ports, the port of Gioia Tauro occupies an intermediate position among the transshipment hub ports with an average value of 34 h and a coefficient of variation of 0.36 (55 observations). The average values of the ports of Algeciras and Tangier Med are lower than the one of Gioia Tauro, respectively with 21 h and a coefficient of variation 0.37 (20 observations) and with 23 h and a coefficient of variation of 0.36 (15 observations). The value in the port of Rotterdam is 28 h with a coefficient of variation of 0.68 h (20 observations). The port of Piraeus and Genova present a value of ship time similar to the one of Gioia Tauro. Piraeus presents an average value of 32,7 h and a coefficient of variation of 0.52 (25 observations) and Genova has an average value of 35 h and a coefficient of variation of 0.64 (14 observations). The average ship time in port is 53 h and a coefficient of variation of 0.51 (15 observations) in the port of Hamburg and it is equal to 46 h with a coefficient of variation of 0.47 (28 observations) in the port of Antwerp. As far as concerns the maximum ship capacity, the hub transshipment ports present similar values that are in the range of 20,000 TEUs and the values of coefficient of variation are, generally, close to 1.

Table 2 shows the number of container ships of the sample examined belonging to a shipping alliance for each port. Gioia Tauro, Valencia and Antwerp present container ships that belong mainly to the 2 M alliance. Algeciras and Piraeus mainly calls container ships that do not belong to any of the three main alliances. In the other ports, container ships are distributed among the three alliances, with a prevalence the 2 M Alliance.

A correlation analysis between the variable ship port time,  $t_p$ , and the attributes considered and among the attributes was carried out. The results of the correlation analysis are reported in Tab. 3. They show that there are two attributes that are higher correlated with the variable port ship time,  $t_p$ . The first attribute is the capacity of container ships in its different specifications, Cap, and the second attribute is the age of the container ships, Age.

**Table 1** Maximum, average, minimum and c.o.v. values of ship time in port ( $t_p$ ) and of maximum ship capacity (Cap)

Ports	N. obs. (*)	$t_p$ , ship time in port(*) [h]			min	c.o.v.(#)	max	Cap, maximum ship capacity(**) [TEUs]			min	c.o.v.(#)
		max	avg	min				avg	max			
Gioia Tauro	55	67	34	12	0.36	22,000	5,723	957	0.99			
Livorno	20	50	27	12	0.38	9,403	4,731	868	0.66			
Genoa	14	79	35	11	0.64	15,000	4,956	698	1.00			
Valencia	28	96	38	14	0.57	13,296	5,423	868	0.81			
Algeciras	20	38	21	7	0.37	23,112	5,216	862	1.18			
Tanger Med	15	37	23	9	0.36	19,462	5,772	1,118	1.07			
Piraeus	25	96	33	16	0.52	19,224	6,530	925	0.93			
Rotterdam	20	81	28	12	0.68	20,038	5,577	700	0.99			
Hamburg	15	103	53	21	0.51	23,112	10,304	868	0.85			
Antwerp	28	96	46	10	0.47	23,964	9,249	2,556	0.53			

Source: (\*) VesselFinder.com; (\*\*) ships.jobmarineman.com; (#) c.o.v., coefficient of variation.

**Table 2** Number of container ships belonging to a shipping alliance for each port

Ports	2 M	OA	TA	OT
Gioia Tauro	31	9	0	0
Livorno	7	3	5	5
Genoa	4	6	2	2
Valencia	14	3	2	9
Algeciras	2	3	1	14
Tangier Med	5	3	1	6
Piraeus	8	6	3	23
Rotterdam	9	6	2	3
Hamburg	2	5	3	5
Antwerp	14	7	2	5

Source: (\*) VesselFinder.com; (\*\*) ships.jobmarineman.com

### 3.2 Calibration results

The model of Eq. (2) was calibrated using the LS method (see Eq. 3). According to the evidences of the correlation analysis, the basic model was specified with the attributes ‘Cap’ and ‘Age’:

$$tp = \gamma_0 + \gamma_{CAP} Cap + \gamma_{AGE} Age$$

The basic considerations concern the model 1 (Table 4) which can be considered as the reference model. The average value of  $\gamma_0 = 14.85$  (t-st=2.86) defines the reference threshold of ship port time for all ports, and it is interesting to note that this value absorbs about the 50% of the average ship port time estimated in the majority of calibrated models (except for models 6, 10, 17 and 18). The value of parameter  $\gamma_{CAP} = 2.84$  (t-st=9.50) indicates that ship port time increases as the port is able to host container ships with larger capacity. The same consideration is valid for parameter  $\gamma_{AGE} = 0.19$  (even if the value of t-student statistics is: t-st=0.72), that is ship port time decreases if the container port calls ships of more recent generations.

Further calibrations have been carried out with more attributes, having the two attributes, Cap and Age, as reference ones (see Tables 4 and 5). Generally, the following elements may be recalled. The calibrated parameters  $\gamma_j$  are positive, that is, as the value of the attribute increases, the value of the ship port time,  $t_p$ , increases. The parameters  $\gamma_{Cap}$  and  $\gamma_{Age}$  have stable positive average values among the different calibrated models. While the values of the t-student statistics for the parameter  $\gamma_{Cap}$  are good, the values of the t-student statistics for the parameter  $\gamma_{Age}$  are always below the acceptable thresholds. The values of the coefficients of determination  $R^2$  and the corrected coefficients of determination  $R^2$  are acceptable.

Among the calibrated models, the following models are discussed in more details.

The model 10 presents a value of  $\gamma_0 = 2.28$  (t-st=0.32). The reduction of  $\gamma_0$  from the reference model 1 is compensated by the values of the other parameters. The positive value of parameter  $\gamma_{Cap} = 2.76$  (t-st=9.37) indicates that the greater the

**Table 3** Correlation matrix

$t_p$	Cap	Age	2 M	OA	TA	OT	PCS	AF	SE	NE	CAP12	CAP16	CAP18	CAP>12	CAP<12	12<CAP<18	CAP>18
1.00																	
Cap	0.63	1.00															
Age	-0.35	-0.61	1.00														
2 M	0.09	0.06	0.13	1.00													
OA	0.08	0.13	-0.13	-0.48	1.00												
TA	0.08	0.12	-0.03	-0.28	-0.17	1.00											
OT	-0.23	-0.28	0.00	-0.50	-0.31	-0.18	1.00										
PCS	0.24	0.11	-0.19	-0.11	0.05	0.17	-0.03	1.00									
AF	-0.15	-0.03	0.05	-0.06	-0.02	-0.02	0.10	-0.37	1.00								
SE	-0.20	-0.24	0.26	0.08	-0.08	-0.03	0.01	-0.31	-0.36	1.00							
NE	0.30	0.27	-0.30	-0.05	0.10	0.05	-0.07	0.53	-0.20	-0.85	1.00						
CAP12	0.11	0.01	0.12	-0.01	-0.06	-0.01	0.08	-0.26	0.10	0.42	-0.49	1.00					
CAP16	-0.07	-0.01	0.08	0.02	-0.01	-0.11	0.06	-0.86	0.31	0.11	-0.30	0.31	1.00				
CAP18	-0.07	-0.03	0.09	0.03	-0.01	-0.15	0.07	-0.82	0.28	0.12	-0.29	0.27	0.95	1.00			
CAP>12	0.59	0.87	-0.56	0.00	0.17	0.06	-0.21	0.05	0.02	-0.22	0.22	0.00	0.09	0.07	1.00		
CAP<12	-0.07	0.03	0.05	0.10	-0.10	0.09	-0.08	0.10	-0.10	0.02	0.03	0.01	-0.19	-0.19	-0.47	1.00	
CAP<12	-0.07	0.03	0.05	0.10	-0.10	0.09	-0.08	0.10	-0.10	0.02	0.03	0.01	-0.19	-0.19	-0.47	1.00	
12<CAP<18	0.33	0.40	-0.29	0.06	0.01	0.15	-0.18	0.13	-0.02	-0.12	0.14	0.03	-0.10	-0.13	-0.33	1.00	
CAP>18	0.46	0.73	-0.46	-0.02	0.18	-0.04	-0.13	-0.03	0.04	-0.18	0.17	-0.02	0.16	0.17	0.80	-0.31	1.00

UoM = Unit of Measure;  $\gamma$  = average value of calibrated parameter; t-st = value of t-student

**Table 4** Values of estimated parameters and of t-student statistic (part I)

	UoM		1	2	3	4	5	6	7	8	9
	--	$\gamma_0$	14.85	14.76	14.81	14.85	14.85	3.73	15.48	16.50	11.18
		t-st	2.86	5.19	5.27	2.85	2.85	5.55	3.02	3.06	2.11
Cap	TEU/10 <sup>3</sup>	$\gamma$	2.84	2.80	2.83	2.83	2.83	2.84	2.83	2.80	2.75
		t-st	9.50	0.30	0.30	9.39	9.39	0.29	9.60	9.33	9.27
Age	Year	$\gamma$	0.19	0.15	0.19	0.19	0.19	0.32	0.23	0.23	0.31
		t-st	0.72	0.27	0.26	0.71	0.71	0.26	0.88	0.88	1.18
2 M	[0;1]	$\gamma$		2.05							
		t-st		2.85							
TA	[0;1]	$\gamma$			0.14						
		t-st			3.33						
OA	[0;1]	$\gamma$				0.18					
		t-st				0.04					
OT	[0;1]	$\gamma$					0.18				
		t-st					0.04				
PCS	[0;1]	$\gamma$						-12.16			
		t-st						-2.36			
AF	[0;1]	$\gamma$							-3.32		
		t-st							-1.14		
SE	[0;1]	$\gamma$								-3.32	
		t-st								-1.14	
NE	[0;1]	$\gamma$									8.10
		t-st									2.64
R2			0.40	0.40	0.40	0.40	0.40	0.43	0.42	0.41	0.42
R <sup>2</sup>			0.40	0.39	0.39	0.39	0.38	0.42	0.40	0.39	0.40

UoM= Unit of Measure;  $\gamma$  = average value of calibrated parameter; t-st = value of t-student

maximum capacity of the container ship is, the greater is the ship time in port. This result is connected to the longer handling times due the higher number of unloading/loading operations of higher capacity container ships. The parameter  $\gamma_{Age} = 0.31$  (t-st = 1.19) is positive, therefore the lower the age of the ship is, the shorter is the ship port time. This could be due to the fact that ships built more recently have on-board equipment that allow more efficient operations. The model has two geographical attributes: Southern Europe, SE, and Northern Europe NE. Their calibrated parameters are respectively:  $\gamma_{SE} = 9.93$  (t-st = 1.91) and  $\gamma_{NE} = 16.91$  (t-st = 3.07). The positive values of these parameters indicate that the ship times in the ports of Southern Europe and Northern Europe are greater than ones experienced in African ports (Tangier Med). The result is important because it establishes some reference thresholds of ship times of the container ports belonging to the three geographical macro-areas.

The model 17 presents two different attributes associated to the maximum ship capacity:  $Cap \geq 12$  and  $Cap < 12$ ; instead of a single attribute of maximum ship

**Table 5** Values of estimated parameters and of t-student statistic (part II)

UoM			10	11	12	13	14	15	16	17	18	
Cap	TEU/10 <sup>3</sup>	---	$\gamma_0$	2.28	14.06	16.27	15.16	14.79	19.70	18.02	3.24	7.08
		t-st		0.32	2.63	3.12	2.89	2.79	3.78	3.40	0.46	1.00
		$\gamma$		2.76	2.73	2.21	2.73	2.85				
Age	Year	t-st		9.37	8.48	4.93	6.90	7.28				
		$\gamma$		0.31	0.12	0.23	0.19	0.19	0.09	0.19	0.36	0.22
2 M	[0,1]	t-st		1.19	0.44	0.88	0.75	0.72	0.36	0.73	1.39	0.84
		$\gamma$			3.60							
TA	[0,1]	t-st			0.97							
		$\gamma$			2.54							
OA	[0,1]	t-st			0.61							
		$\gamma$			2.74							
SE	[0,1]	t-st		9.93							10.97	10.64
		$\gamma$		1.91							2.12	2.00
NE	[0,1]	t-st		16.91							18.08	17.55
		$\gamma$		3.07							3.29	3.09
Cap $\geq$ 12	TEU/10 <sup>3</sup>	t-st						2.75		2.80		
		$\gamma$							9.13	9.57		
Cap < 12	TEU/10 <sup>3</sup>	t-st						1.99		1.98		
		$\gamma$							4.00	4.07		
Cap < 12	TEU/10 <sup>3</sup>	t-st							1.96		1.75	
		$\gamma$								3.96	3.52	
12 $\leq$ Cap $\leq$ 18	TEU/10 <sup>3</sup>	t-st							3.06		2.50	
		$\gamma$								7.11	6.27	
Cap > 18	TEU/10 <sup>3</sup>	t-st							2.68		2.41	
		$\gamma$								8.42	7.87	
R2			0.43	0.40	0.41	0.40	0.41	0.40	0.41	0.44	0.42	
R $\bar{2}$			0.42	0.38	0.40	0.39	0.39	0.39	0.39	0.43	0.40	

capacity, Cap, as in models 1 and 10. As far as concerns the parameters  $\gamma_{Age}$ ,  $\gamma_{SE}$ ,  $\gamma_{NE}$ , the comments are similar to the case of model 10. The use of two attributes of capacity was introduced in order to highlight possible non-linearity effects in the capacity attribute (2-class capacity). The result of the calibration is that the ship port time increases as the maximum ship capacity increases; as matter of fact, the parameter  $\gamma_{Cap>12} = 2.80$  (t-st=9.57) is greater than the parameter  $\gamma_{Cap<12} = 1.98$  (t-st=4.07). This means that container ships that have a capacity greater than 12,000 TEU have a greater impact on the ship port time.

The model 18 differs from models 10 and 18 because it presents three different attributes of maximum ship capacity:  $Cap > 18$ ,  $18 \geq Cap \geq 12$ , and  $Cap < 12$ . The values of the parameters ( $\gamma_{Age}$ ,  $\gamma_{SE}$ ,  $\gamma_{NE}$ ) have been discussed in the case of model 10. According to the capacity parameters, the ship port time increases as the maximum capacity of ships increases. It is worth noting that parameter associated to ships with capacities between 12,000 TEU and 18,000 TEU is greater than the

parameters associated the other two classes. This means that longer ship port times are associated to this class of container ships. The fact that the parameter associated to capacity greater than 18,000 TEU, has a lower value than the parameter associated to capacity between 12,000 TEU and 18,000 TEU, could be justified that the latest generation ships (Ultra Large Container Ships - ULCS and New Panamax types) have priority over the ships of previous generations in the container ports considered in the analysis.

## 4 Conclusions

The port ship times are a useful benchmark for evaluating ports' ability to efficiently handle container flows within their terminals. In the literature, ports are generally studied as individual systems and there is no transversal knowledge about ports. The approach proposed is fruitful because it allows to test the level of dependency of ship port times from some attributes at port level.

The calibrated parameters could help to better identify the determinants that influence the ship port times at port level in order to identify and prioritize measures at local level and at national (country) level able to contribute to the reduction of the ship port times, and then to efficiently handle container flows inside ports and terminals.

There is a wide range of measures for ports that can be grouped into four categories: (a) measures relevant to physical infrastructures, that can be divided into sea-side infrastructures (e.g. breakwaters, quays, draught, ...) and landside infrastructures (e.g. loading/unloading areas, last-mile connections with terrestrial networks; ...); (b) measures on equipment, relevant to loading/unloading units and/or transport units (e.g. low impact vehicles); (c) measures relevant to immaterial infrastructures, such as research and education, emerging information and communication technology; (d) measures related to governance (e.g. special economic zones).

It is worth recalling here two categories of measures that generate the main impacts of port ship times. The first category is connected to the internal structural factors of a container (third-generation) port, considered as a 'fabric with its internal production processes' operating inside port areas. The port production is based both on physical (material) components, such as transport and logistic infrastructures, and on intangible (or immaterial) components, such as the research and education ones. The second category of measure relates with administrative simplification.

The results obtained are useful for the technicians of port authorities because they allow to build a benchmark among container ports. The results are also useful for deciding national-scale policies for investments in ports, in order to optimize the resources used by improving the performance of port systems. The methodology used and the attributes investigated are useful for the development of the research, considering that, as mentioned in the introduction, the research directions relating to the reduction of port ship times tend to analyze the specific elements connected to the processing of the single ship, disaggregating the whole port ship time into times relating to single operations performed on ships.

Further developments are necessary on two main research directions. The first direction concerns the extension of the analysis on other container ports and the investigation about the influence of further attributes. It is also useful to investigate the impacts of the different generations of PCS on the port ship times. The second direction requires further comparisons with more theoretical approaches and tools (such a network models, recalled above; combinatorial optimization, Markov chains) in order to consolidate the results obtained by means of the approach presented.

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