The influence of the characterisation factors of the European ports on operational performance: Conceptual model testing

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Abstract: The study analyses the relationships between the characterisation factors and the operational performance of ports. The research model, based on performance theory, suggests the existence of a set of relationships between several factors that characterise ports, and argues that they influence the ports' operational performance. Drawing on path analysis methodology supported by structural equation modelling (SEM), the results obtained from a sample of 43 of the largest European ports indicate that relationships between location, specialisation, size, shipping services and infrastructure, and operational performance do exist. The study also identifies the independent and mediating variables.

Keywords: European ports; operational performance; characterisation factors; structural equation modelling; SEM; path analysis.

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1 Introduction

Globalisation, resulting from trade growth between continents, regions and countries, led to an increase in the importance and development of seaborne trade and ports worldwide. Moreover, the increased loading capacity of vessels requires ports to have a higher operational performance, which largely depends, among other factors, on port characteristics, such as infrastructure, facilities, governance structure and their integration in global maritime networks.

Ports became logistic platforms, providing value and benefiting from transit times. These conditions affect performance, but according to Tongzon and Heng (2005), they also provide ports with international competitive advantages. In such a context, the importance of both containerisation and globalisation on the operational changes to ports was characterised by a growing level of integrated liner services transportation systems (Cullinane and Song, 2005; Juang and Roe, 2010). The development of transport infrastructures, the increase in vessel size and the choice of ‘hub-ports’ serving growing ‘hinterlands’ have therefore dramatically increased competition among ports (Wang and Cullinane, 2006). This, according to Haralambides (2002), and Notteboom and Rodrigue (2005), has in turn triggered the need to increase cargo throughput to support economic growth.

Few studies have analysed port performance (Gonzalez and Trujillo, 2009), and most authors address the question of performance by simply comparing ports and port terminals without explaining their differences or understanding the reasons why some ports perform better than others (Trujillo and Tovar, 2007; Estache et al., 2005; Turner et al., 2004; Wu and Liang, 2009; Ablanedo-Rosas and Ruiz-Torres, 2009; Liu and Medda, 2009).

This study aims to understand how port characterisation factors determine operational performance, and analyses the type and significance of these factors. The premise is that ports with different locations experience different degrees of integration in global chains, develop specialised services and provide different types of infrastructures, aiming to assure greater competitiveness and achieve competitive advantages while contributing to the development of the port industry. Research supports the port performance theory to examine the causal relationships between port characterisation factors and their operational performance, as well as the nature and the extent to which mediating variables influence that relationship.

After the introduction, this paper presents the theoretical background, the research methods used, including the adopted model, hypotheses and variables, data collection and instruments. The next section describes the results obtained, followed by the discussion. After the conclusions, we outline the management implications and put forward potential avenues for future research.

2 Theoretical background

Market concentration in a region provides companies with an edge, allowing them to benefit from economies of scale compared to peripheral markets (Helpman and Krugman, 1985; Combes et al., 2008). This, according to Ottaviano and Van Ypersele (2005), explains why transport infrastructure improvements can aggravate regional disparities and lead to increased congestion in the core economic region. This suggests that ports located in such regions are more likely to attract companies and thus to expand and further improve their infrastructures, resulting in enhanced competitiveness when compared to more remote regions.

The degree of port efficiency partly determines the competitivity of regions and countries. According to Behrens et al. (2006), coastal economies, countries with seaports and cabotage shipping, have an advantage over landlocked countries as they reduce the distance to trade partners and thus provide economic benefits in terms of GDP growth.

Bichou (2007) considers port performance a broad concept, covering almost any objective of operational management and competitive excellence of a company and its activities. He suggests that efficiency and utilisation dimensions interact with quality and effectiveness, though he acknowledges that few studies take place at multi-institutional and cross-functional port sector levels. Likewise, Brooks and Cullinane (2007) indicate that little research is carried out on service quality, and its relation to performance indicators. Hence, the need for further investigation taking based on port performance theory. For example, Wilson et al. (2003) report that poor port performance can reduce port activity, especially in small ports and less developed countries, whereas Turner (2000) defines a model to analyse seaport performance as opposed to terminal performance. He does not however take into account other relevant affects on performance.

This study focuses on port performance theory, namely operational results, which are dependent on port characterisation factors responsible for their competitive advantage conditions and development. In this regard, literature on port models (Notteboom and Rodrigue, 2005) analyses the performance from various perspectives (Brooks and Cullinane, 2007; Chang and Lee-Paul, 2007; Tongzon and Heng, 2005; Kamble et al., 2010) and how factors such as location, infrastructure, logistic integration, amongst others, influence it (Song and Yeo, 2004; Turner et al., 2004; Estache et al., 2001; Liu, 1995; Notteboom, 2010; Wilmsmeier et al., 2011). For instance, infrastructures facilitate ship operations, cargo handling, storage and other intra-port operations contributing to the overall efficiency and performance of ports and terminals (e.g., Cullinane and Song, 2005; Tongzon and Heng, 2005). Several authors, including Song and Yeo (2004), Barros (2003), Trujillo and Tovar (2007), Garcia-Alonso and Martin-Bofarull (2007), and Park and De (2004), use port throughput as an output variable in performance model analysis.

Port location seems to be a key determinant of port performance (Liu, 1995) and perhaps the most important one, given that port activity is not usually self-generating, except in the case of ports exclusively handling transshipment cargo. Song and Yeo (2004) argue that the volume of cargo handled is strongly influenced by a port's geographic location, which usually cannot be changed. Evidence shows that not only are ports located in smaller economies affected in terms of port throughput and performance, but also that the port demand is driven by the close proximity to traffic flows and consumption regions (Tongzon and Heng, 2005). The implication is that port performance is influenced by the economic activity of the nearest region, although port characteristics may have a bearing on this relationship.

Accordingly, the proximity to economically developed regions influences port activity (Frémont and Franc, 2010), whereas characteristics such as the level of infrastructure and equipment investment as well as accessibility, influence port performance.

As previous studies show, port size is considered to be a determinant variable influencing port performance (Liu, 1995; Wiegmans, 2003), due to the existence of economies of scale (Hung et al., 2010). Evidence shows that port productivity increases with size driven by significant economies of scale, which suggests that a greater degree of investment is concentrated in large-sized ports rather than in small ones (De-Neufville and Tsunokawa, 1981). Other studies note a learning effect in large-sized ports, which helps to improve performance (Estache et al., 2005; Turner et al., 2004; Gonzalez and Trujillo, 2009).

However, dimensional factors associated with economies of scale, location and regional concentration can lead to under-utilisation of port capacity (Barros and Peypoch, 2007), which undermines the use of port size concept based on infrastructure.

Liu (1995) argues that investment in port infrastructures is one of the factors that can explain performance differences between ports, because without port facilities or their service capacity, ports would be unable to handle the increasing growth in the amount of cargo and the number of vessels. Berth capacity is a significant input variable, which strongly influences port operational performance (Park and De, 2004).

Garcia-Alonso and Martin-Bofarull (2007) took a period of major investment in the ports of Bilbao and Valencia as their starting point and concluded that the same levels of infrastructure investment do not always lead to equivalent improvements in port performance. This indicates that further study of other factors, such as location and hinterlands, among others, is required.

Chlomoudis et al. (2003) suggest that ports need to provide both generic services with a standardised, predefined process, as well as dedicated services responding to individual demand and based on the mobilisation of specialised resources. Maritime accessibility is a determining element for a port to be able to increase its market share and allows port users to enjoy shipping economies of scale in the form of substantially lower freight costs. The success of liner services in a hub-and-spoke system resulting from economies of scale achieved at sea should not be negated by diseconomies of scale in ports (Lun and Cariou, 2009).

Turner et al. (2004) studied the impact of land and maritime accessibility and Gaur (2005) identified six factors affecting port performance: maritime accessibility, berth facilities, terminal infrastructure, storage facilities, services and hinterland.

Port specialisation linked to containerisation was documented by Trujillo and Tovar (2007), and Medda and Carbonaro (2007) and it reflects the port's transition from the industrial phase to the modern and commercial one. Tongzon and Heng (2005) state that the service frequency of vessels allow shippers to benefit from a wider array of service choices, greater flexibility and smaller transit times, with a positive impact on port performance. Equally, port selection of carriers are decided according to their service networks and partnerships (Tongzon and Heng, 2005), which is why it is essential for ports to be integrated in global carrier networks, who provide worldwide shipping services to major ports and global logistic chains.

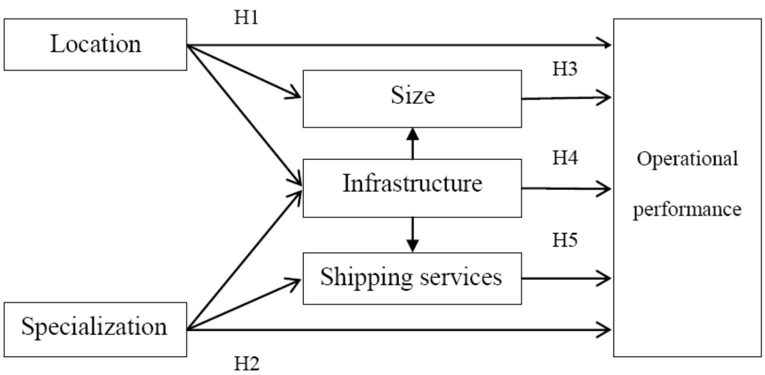
Veldman and Bückmann (2003) studied the impact of port market shares on port performance in Northern Europe, using factors such as service frequency and vessel transit time. Turner et al. (2004) analysed the impact of shipping services and port facilities on port performance.

3 Research methods

3.1 Conceptual model and hypothesis

Based on existing literature, we defined a conceptual model of relationships between port characteristics, identified as location, size, infrastructure, specialisation and shipping services, and operational performance, with some of these as mediating variables. These resulted in research hypotheses (Figure 1).

Figure 1 Conceptual model



The construction or development of a port depends on its location and determines its operational performance (Liu, 1995; Song and Yeo, 2004; Tongzon and Heng, 2005), because the proximity to round-the-world maritime routes or to the main markets and international suppliers provides an opportunity to be part of regional and global supply chains.

However, the size of the port and its infrastructures can also play a role. By improving and scaling their characteristics and facilities to respond to the needs of neighbouring markets and the hinterland, they can benefit from economies of scale. This forms the basis of the first hypothesis:

Hypothesis 1 Port location influences operational performance, either directly or combined with size and infrastructure.

Port specialisation affects investment and directly influences shipping services as well as performance (Trujillo and Tovar, 2007; Medda and Carbonaro, 2007), particularly when liner services are attracted by specialised container and general cargo terminals.

Similarly, a relationship between the type of infrastructure and the port specialisation is acknowledged, as it affects the physical characteristics of the port and its operational performance. This forms the basis of the second hypothesis:

Hypothesis 2 Port specialisation affects operational performance, either directly or combined with shipping services and infrastructure.

Port size is considered a major factor given its influence on operational performance (Liu, 1995; Wiegmans, 2003; Hung et al., 2010; De-Neufville and Tsunokawa, 1981; Estache et al., 2005; Turner et al., 2004; Gonzalez and Trujillo, 2009), due to the effect of economies of scale. This forms the basis of the third hypothesis:

Hypothesis 3 Port size has a positive effect on its operational performance.

It is assumed that port infrastructure, especially the maritime accesses, the terminals and the facilities affect the type of ship calling at the port and the shipping services provided at the port. They also affecting port size and its operational performance (Turner et al., 2004; Gaur, 2005). This forms the basis of the fourth hypothesis:

Hypothesis 4 Ports with better infrastructures boast better operational performance, either directly or in combination with shipping services and port size.

The type of shipping services provided by vessels calling at the port determines its operational performance, since the shippers choose the port according to the type and level of shipping services offered and the frequency and size of vessels (Tongzon and Heng, 2005; Veldman and Bückmann, 2003). This forms the basis of the fifth hypothesis:

Hypothesis 5 Improved shipping services have a positive impact on a port's operational performance.

3.2 Constructs and variables

The conceptual model consists of six formative constructs, or composite latent variables, and 15 observed variables, or causal indicators. Each construct is a composite latent variable of observed variables that represents its main dimensions or measurements (Table 1).

Port location is used to represent the geographic position in relation to the Centre of Europe and to the major economic port and shipping routes. It is acknowledged that there is a high concentration of traffic in the port range centred around the port of Rotterdam, between Le Havre and Hamburg. The greater the distance from the ports in that range, the greater the distance to Europe's logistic and economic centre, something that influences the port's operational performance. It is defined as a composition of variables, and these include the distance to Rotterdam, the logistic Centre of Europe (DISTROTTERDAM). Distance to the Mediterranean axis is also used because of its proximity to the major round-the-world and Asia-Europe axis. Going through the Mediterranean is also considered a factor influencing the operational performance of the ports, especially as a potential transshipment hub in crossing this axis with feeder axes of the Mediterranean and the North-South axis and links between the Atlantic and Northern Europe (DISTMEDITERRANEO). The seaport or inland/estuary port variable is also considered, since the conditions for receiving larger vessels in seaports, as well as the lowest shipping time from the main routes may affect operational performance (SEARIVERPORT). Distance to the nearest city is used because the 'any port development model' redesigned by Notteboom and Rodrigue (2005) points to a gradual distancing of ports and cities with the goal of seeking more land for logistic and industry purposes, as well as better maritime access, which influences port performance

(DISTCITY). Another variable of port location is the economic activity of the region where the port is located (GDPPERCAPITA), which constitutes the natural hinterland of the port and influences a port's operational performance.

Table 1 Variables

Variable	*Construct*	*Description and authors*
DISTROTTERDAM	Location	The distance to Rotterdam port was calculated by drawing a straight line between each port taken from the sample and the maritime entrance to Rotterdam port, in kilometres, with reference to the (geographical) meridian. It is a continuous variable greater than zero. Source: Authors calculations (Song and Yeo, 2004; Ugboma et al., 2006; Yeo and Song, 2006; Liu, 1995; Estache et al., 2001).
DISTMEDITERRANEO	Location	The distance to the Mediterranean axis was calculated in kilometres by drawing a straight line beginning on the meridian of each port taken from the sample and ending in the central point between the shores of the Mediterranean Sea, which cross the same meridian, with reference to the (geographical) meridian. It is a continuous variable greater than zero (Song and Yeo, 2004; Ugboma et al., 2006; Yeo and Song, 2006; Liu, 1995; Estache et al., 2001). Source: Authors calculations.
SEARIVERPORT	Location	The variable is a dummy variable that assigns the value of 1 if the port is on the coastline and the value of 0 if the port is located on an estuary or river. Source: survey (Gonzalez and Trujillo, 2009).
DISTCITY	Location	The distance to the nearest city is calculated by a straight line from each port sample to the closest urban centre, measured in kilometres. Source: survey (Notteboom and Rodrigue, 2005; Fleming and Baird, 1999).
GDPPERCAPITA	Location	The performance of the region in which the port is located and its economic influence is measured by the ratio between GDP and the population of the NUTS II region as a percentage of average European Union (EU27 = 100), where each port is located (Regional Yearbook 2008, Eurostat). Source: Authors calculations.
QUAYSIZE	Size	The total quay length in metres refers to the size of the port built infrastructure and corresponds to the sum of all operating terminal quay lengths over 4 metres of depth (Coto-Millán et al., 2000; Liu, 1995). Source: survey.
NBCRAINSPERKM	Infrastructure	The number of cranes per kilometre of quay is obtained by dividing the number of quay cranes, regardless of type or function, by the total quay length of operational terminals, in kilometres. Source: survey.

Table 1 Variables (continued)

Variable	*Construct*	*Description and authors*
TERMINALSSIZE	Infrastructure	The average terminal size is obtained by dividing the total tonnage handled at the port by the number of port terminals, within dependent management and physically separated, resulting in the average throughput by terminal, measured in tons. Source: survey.
MAXMARITIMEDRAFT	Infrastructure	The quay depth, in metres, is the distance between quay depth and the hydrographic zero of the terminal with deeper water depth. It is a continuous variable, greater than zero. Source: survey (Wang and Cullinane, 2006; Guy and Urli, 2006).
UNITIZRATE	Specialisation	The ‘unitisation’ rate corresponds to the ratio between general cargo traffic and total throughput, measured in tons. General cargo includes break-bulk cargo, containerised cargo and roll-on-roll-off cargo. Source: survey.
HORIZONTALRATE	Specialisation	The ‘horizontalisation’ rate is calculated by dividing the roll-on-roll-off cargo by general cargo handled, measured in tons. When this value tends to 1, it means the port is specialised in roll-on-roll-off cargo, as a part of general cargo. Source: survey.
CONTAINERRATE	Specialisation	The ‘containerisation’ rate of general cargo is the ratio between containerised cargo and general cargo handled at the port, being the most adaptable cargo to be transported in containers. It is a continuous variable, between zero and one (Trujillo and Trovar, 2007; Hui et al., 2004). Source: survey.
REGULARLINES	Shipping Services	The ratio between the number of liner services and the total number of port calls is used to define shipping services and takes the form of a continuous variable, between zero and one, and aims to emphasise the importance of direct liner services in the port (Ugboma et al., 2006; Yanbing and Zhongzhen, 2005; Turner et al., 2004). Source: survey.
SHIPSIZE	Shipping services	The average size of vessels calling at a port, measured in tons of ‘gross tonnage’, is a continuous variable, greater than zero (Turner et al., 2004). Source: survey.
TOTALTON	Operational performance	Port operational performance variables are identified by total throughput, measured in absolute value, in terms of tons (Song and Yeo, 2004; Barros, 2003; Trujillo and Tovar, 2007; Garcia-Alonso and Martin-Bofarull, 2007; Park and De, 2004; Coto-Millán et al., 2011). Source: survey.

Port size comprises the total quay length (QUAYSIZE), a variable used by several authors.

Infrastructures are characterised by the level of operation of built infrastructure and measured by the number of cranes per kilometre of quay (NBCRAINSPERKM), the average size of terminals (TERMINALSSIZE) and the quay depth (MAXMARITIMEDRAFT), all variables used in a number of papers on ports.

Port specialisation represents the specialisation of cargo handling and it is identified by specialisation rates. It is measured by the unitisation rate (UNITIZRATE), horizontalisation rate (HORIZONTALRATE) and containerisation rate (CONTAINERRATE). The containerisation rate is used in several papers, but the other ratios have been used for the first time. The unitisation rate defines the port as a bulk port or a general cargo port, which influences the type of infrastructure, shipping services and performance. The horizontalisation rate discriminates the major roll-on roll-off ports in the north and south of Europe, which influence the infrastructure, shipping services and performance.

Shipping services account for the vessel characteristics and organisation of liner shipping and are measured by the relationship between the number of liner services and the number of vessel calls (REGULARLINES) and by the average ship size (SHIPSIZE). The share of regular lines in the port is important when defining the type of shipping regular services that are calling at the port, versus the tramping calls in bulk and break-bulk markets, influencing the port performance. The size of the ships calling at the port is determinant of the shipping market level offered by the port, affecting port performance.

Port operational performance is measured using the variable total throughput (TOTALTON), including all the cargo that uses the port services, as a variable of the performance success, and is used by almost all authors.

4 Data collection/sample and instruments

The data refer to 2008 and were collected from a universe of the 230 largest European ports, obtained from the European Sea Ports Organization (ESPO) 2007 to 2008 Annual Report. Surveys were sent electronically to the port authorities' top managers. Reminders were sent to non-respondents resulting in 64 answers, of which a final sample of 43 valid responses was obtained (Annex).

The study used the path analysis method supported by structural equation modelling (SEM). SEM is a comprehensive approach to testing hypotheses about relations among observed and latent variables (Hoyle, 1995). The statistical approach incorporates path analysis and linear regression (Hair et al., 2006) into a theoretical causal model for analysis of latent constructs and measurable variables, allowing simultaneous estimation of both measurement and structural sub-models. The study used AMOS programme version 5.0 (Arbuckle, 2004) to estimate the path coefficient of the relationship between the variables in the model.

The path analysis is a method that is undoubtedly useful in studying causal structures in all disciplines of science. Scientists should take account of its dynamic development in the past two to three decades and try to apply the novel estimation approach in their research. Without this, studying causal associations in science will lag behind other scientific disciplines where new path analysis methodology is being put into practice

(Kozak and Kang, 2006). Traditional multivariate modelling, linear regression, ANOVA and logistic regression are useful for examining direct relationships between independent and dependent variables: dependent variable is a function of independent variable 1 and independent variable 2 and independent variable n. However, reality is not so parsimonious and relationships between various variables are much more complex. This 'web' of relationships could not be easily modelled with standard regression techniques. This said, SEM readily allows one to explore such complex interrelationships. Path analysis is a subset of SEM, the multivariate procedure that, as defined by Ullman (1996), allows one to examine a set of relationships between one or more independent variables, continuous or discrete, and one or more dependent variables, continuous or discrete.

The goal of the estimation is to produce a $\Sigma(\theta)$ that converges upon the observed population covariance matrix S (Ullman 1996), while minimising the residual matrix (the difference between $\Sigma(\theta)$ and S). The minimisation function is $Q = (s - \sigma(\theta))'W(s - \sigma(\theta))$, where, s = vector containing the variances and covariances of the observed variables, $\sigma(\theta)$ = vector containing corresponding variances and covariances as predicted by the model and W = weight matrix.

5 Results

In descriptive statistics, the normal distribution of variables was observed, and we can confirm that European port activity is concentrated in a few main ports or 'hub ports' and there are many small and medium-sized ports, which influence the distribution of the variables (Table 2).

Table 2 Descriptive statistics

	N	*Mean*	*Std. deviation*
DISTROTTERDAM	43	1,148.65	670.777
DISTMEDITERRANEO	43	1,226.53	848.101
SEARIVERPORT	43	0.72	0.454
DISTCITY	43	3.59	5.865
QUAYSIZE	43	8,510.19	13,246.584
NBCRAINSPERKM	43	3.62793	3.033383
TERMINALSSIZE	43	2.48E+06	2.72E+06
MAXMARITIMEDRAFT	43	13.73	4.525
UNITIZRATE	43	0.4387456	0.30757091
HORIZONTALRATE	43	0.2114998	0.29902372
CONTAINERRATE	43	0.352236	0.31767226
REGULARLINES	43	0.0039209	0.0033917
SHIPSIZE	43	5,655.55814	5.33E+03
GDPPERCAPITA	43	90.05	25.548
TOTALTON	43	23,285,127.1	3.61E+07

Table 3 Pearson correlation

		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
DISTROTTERDAM	1	1													
DISTMEDITERRANEO	2	–0.372*	1												
SEARIVERPORT	3	0.079	–0.093	1											
DISTCITY	4	–0.014	–0.01	–0.098	1										
QUAYSIZE	5	–0.335*	0.126	–0.351*	–0.012	1									
NBCRAINSPERKM	6	–0.001	0.09	–0.321*	0.072	0.004	1								
TERMINALSSIZE	7	–0.099	0.192	0.066	–0.105	0.121	0.217	1							
MAXMARITIMEDRAFT	8	0.023	–0.363*	0.232	0.283	0.23	0.076	0.021	1						
UNITIZRAT	9	0.108	0.214	–0.08	–0.208	0.088	–0.353*	–0.033	–0.430**	1					
HORIZONTALRATE	10	–0.253	0.306*	0.256	0.004	–0.111	–0.420**	0.11	–0.241	0.544**	1				
CONTAINERRATE	11	0.053	–0.26	–0.073	–0.037	0.328*	0.277	0.063	0.391**	–0.199	–0.297	1			
REGULARLINES	12	0.117	–0.311*	–0.109	–0.006	0.312*	0.136	–0.169	0.264	–0.068	–0.315*	0.619**	1		
SHIPSIZE	13	–0.091	–0.24	0.048	0.257	0.219	0.177	0.089	0.703**	–0.580**	–0.373*	0.321*	0.312*	1	
GDPPERCAPITA	14	–0.464**	0.274	0.044	0.031	0.303*	–0.385*	–0.057	0.069	0.198	0.371*	0.04	0.239	0.025	1
TOTALTON	15	–0.420**	0.043	–0.320*	0.083	0.829**	0.173	0.164	0.319*	–0.038	–0.119	0.435**	0.399**	0.438**	0.313*

Notes: *Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

The Pearson correlation indexes between variables are significant. The results show a correlation between port location and size, infrastructure and performance and between port specialisation and infrastructure, shipping services and port performance. In addition, the results suggest a correlation between infrastructure and shipping services and between these two factors and port performance. Finally, port size has a strong correlation with port performance (Table 3).

5.1 Structural equation modelling

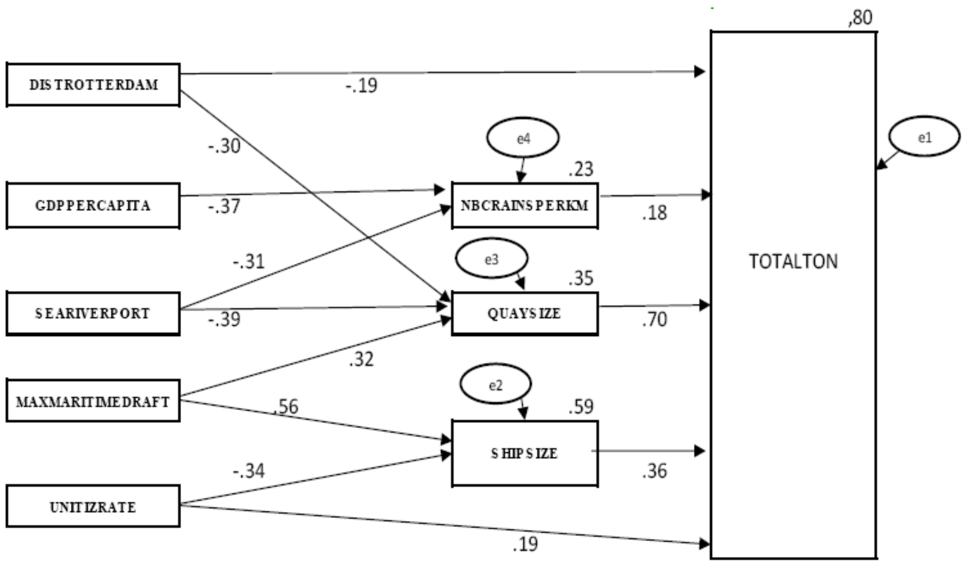
The SEM was applied with a conceptual formative model, using composite constructs and causal indicators or observed variables, but the results were not significant.

Then, the observed variables were applied in the SEM model without composite latent variables, and significant results were obtained as shown in Figure 2.

The path analysis with SEM was applied to confirm the degree of significance of the model and hypothesis, including the relationships between observed variables and between these and performance.

TOTALTON was the operational performance variable used. The results confirm that the relationships between these variables are highly significant, within the framework of the variables relationships expected from the pre-defined model. The variable MAXMARITIMEDRAF, that appears in SEM results as an independent variable, differently from the conceptual model, but has major effects on shipping services and indirectly on port operation performance mediated by port size.

Figure 2 SEM results for port performance



A high significance was obtained with goodness of fit: $\chi^2 = 24.449$ with $p = 0.324$ (> 0.05), $\chi^2/df = 1.111$ (< 5) and with the results CFI = 0.983 (> 0.9), IFI = 0.984 (> 0.9), TLI = 0.972 (> 0.9), NFI = 0.863 (> 0.8) and RMSEA = 0.051 (< 0.06). This result shows a good fitting of the model and its unidimensionality validity (Hair et al., 2006).

From these, it became clear that both distance to Rotterdam (DISTROTTERDAM; $p = 0.014$) and being a seaport or river/estuary port (SEARIVERPORT; $p = 0.002$), two location variables, influence port size (QUAYSIZE), which is also affected by the water depth of maritime accesses (MAXMARITIMEDRAFT; $p = 0.009$), an infrastructure variable.

It is observed that port location, whether seaport or river/estuary one (SEARIVERPORT, $p = 0.023$), and the region's economic performance (GDPPERCAPITA, $p = 0.006$) influence infrastructure through the port facilities variable (NBCRAINSPERKM).

Shipping services, through average ship size variable (SHIPSIZE), are influenced by specialisation, measured by unitisation rate (UNITIZRATE, $p = 0.002$) and port infrastructure, measured by water depth (MAXMARITIMEDRAFT, $p < 0.001$).

Finally, we observed that the port operational performance (TOTALTON) is directly influenced by location, through distance to Rotterdam (DISTROTTERDAM; $p = 0.012$), infrastructure (NBCRAINSPERKM; $p = 0.012$), port size (QUAYSIZE, $p < 0.001$), shipping services (SHIPSIZE; $p < 0.001$) and specialisation (UNITIZRATE, $p = 0.022$).

The influence of port specialisation on infrastructure could not be shown, so the role of the mediating variable infrastructure applies only in the indirect relationships between the location and the operational performance of the port.

The results obtained for the GDPPERCAPITA variable, although significant, have an unexpected contradictory sign, which can be explained by the difference between the number and capacity of quay cranes, due to the fact some ports can have a large number of cranes with reduced capacity, while other, more modern ones have a larger capacity with fewer but bigger quay cranes.

The squared multiple correlation indexes of mediating and dependent variables show that the operational port performance is well explained by the model (SHIPSIZE, $r = 0.589$; NBCRAINSPERKM, $r = 0.234$; QUAYSIZE, $r = 0.352$; TOTALTON, $r = 0.805$).

As far as the total standardised effects are concerned, the QUAYSIZE variable is most significant to port operational performance ($r = 0.702$), followed by port water depth (MAXMARITIMEDRAFT, $r = 0.426$), distance to Rotterdam (DISTROTTERDAM, $r = -0.399$), shipping services (SHIPSIZE, $r = 0.359$), port location by the sea or river (SEARIVERPORT, $r = -0.330$), quay infrastructure/facilities (NBCRAINSPERKM, $r = 0.177$), region's economic performance (GDPPERCAPITA, $r = -0.066$) and specialisation (UNITIZRATE, $r = 0.070$).

6 Discussion

This study confirms that port location and specialisation are the main independent factors, whereas port size, infrastructure and shipping services are mediator factors, as defined in the theoretical framework model and in the hypothesis.

Port location is considered one of the most important characteristics when determining port operational performance directly, or through port size and infrastructure. In fact, the proximity to economically developed regions, like the Centre of Europe, is essential and determines the port's remaining characteristics and performance. Therefore, port location is a relevant factor affecting performance, which is consistent with the results obtained by Estache et al. (2001) and Liu (1995), as are port size and accesses (infrastructure), since they stem from the development and performance of the hinterland, regardless of dimension or economic significance.

The proximity to Rotterdam port, the European logistic and economic centre, has great importance in the port's operational performance, measured by cargo tonnage. The results could not demonstrate the importance of the proximity to the Mediterranean axis, where the main shipping routes cross in 'round-the-world' services. The study also found that there is a relationship between location and port size, which is consistent with the fact that the largest European ports are located in the north of Europe due to their privileged access to the main trade routes and traffics.

There was no relationship found between distance from the cities and better port performance, perhaps because many large European ports with better performance are traditionally close to urban areas and away from the sea, in inland rivers and estuaries. Evidence shows that port location in rivers/estuaries has great significance when trying to explain port operational performance. From a historical perspective, European cities are still served by main inland river ports. Nevertheless, location is an important characterisation factor of port performance and there is no doubt that two ports with similar characteristics can have different performance levels depending on their location relative to consumption and production centres, or to main trade routes.

The economic development level of the region where a port is located has a significant impact on port performance, as it is closely linked to the development of port activity. Therefore, Hypothesis 1 was confirmed because the port location directly affects a port's operational performance, as well as through port size and infrastructure.

This study not only confirmed the relationship between port specialisation and shipping services, but also between port specialisation and port performance. Ports specialising in general cargo have different shipping services from those specialising in bulk cargo, depending on infrastructure. Ports specialised in bulk cargo usually have deeper maritime accesses and less quay length and attract tramping service vessels, cruise charters with deeper drafts; whereas ones specialising in general cargo are usually associated with regular liner services. The results reveal the importance of port specialisation and its effect on port performance, specifically through unitisation rate, which includes containers, because it reflects the port's development stage, the gradual transition from an industrial port to a modern commercial one. The study does not however demonstrate the importance of the containerisation rate and its effect on port performance, as argued by Trujillo and Tovar (2007), and Medda and Carbonaro (2007), perhaps due to the fact that it is best represented by unitisation rate, which also includes ro-ro cargo, break-bulk cargo and containerised cargo.

We were also unable to demonstrate the relationship between port specialisation and infrastructure, with the variables used.

Moreover, ports with higher specialisation in handling general cargo usually achieve higher performance levels in terms of total throughput. Part of the Hypothesis 2 was confirmed. Port specialisation directly affects operational performance as well as through shipping services.

The results referring to port size are consistent with De-Neufville and Tsunokawa (1981) who concluded that port efficiency increases with size due to economies of scale, which led them to recommend investing in large ports while acting with caution when investing in small ones. Nevertheless, small ports play an important role with regard to local economic impact, despite their lower performance in absolute terms. Above all, Estache et al. (2001, 2005), Turner et al. (2004), and Gonzalez and Trujillo (2009) suggested that the larger ports have higher performance levels due to the learning effect offered by greater port activity levels.

The port size is a factor that determines port performance, due to the existence of economies of scale, learning effects, 'hub' effect and other attractor factors, although special attention should be given to understanding whether it is an explanatory variable or an explained one, especially with regard to operational performance. Hypothesis 3 was confirmed. Port size has a positive effect on a port's operational performance

Ports with deeper maritime accesses can handle increasingly larger vessels and regular shipping services. Ports with a higher number of cranes per kilometre of quay (or higher capacity) can operate larger liner vessels with limited waiting times. The investment in port infrastructure is another factor that explains differences in performance among ports, as illustrated by Liu (1995), since the quality of the infrastructure is a determinant when trying to explain productivity and adaptability to seaborne trade, thereby contributing to port performance. The higher the productivity and adaptability of port infrastructure to accommodate growing demands from port users in cargo handling and vessels calls, the more competitive the port is at affecting performance.

This study demonstrates that the number of cranes per kilometre of quay is an important variable when explaining a port's operational performance in terms of total throughput. So a higher quay operational performance, by providing a large number of quay cranes per vessel/quay and faster cargo handling, reduce vessel's turnaround times, handling costs and port dues per ton, and effect the port's operational performance. Port infrastructure is an important variable that affects performance level, although it should be combined with the remaining variables, as it is not a sufficient condition.

Both maritime and inland accessibilities affect port infrastructure, because improved water depth of navigation channels allows larger vessels to call at the port, higher productivity rates per quay and increases total throughput for the same quay length.

The study also confirms that port water depth can explain the port's operational performance, not only directly but also through size and shipping services. In fact, deepening navigation channels is an essential infrastructure upgrade for ports, involving major investment in dredging or building breakwaters with a significant improvement to port supply services.

The average size of vessels in the world's shipping fleet is continually growing, with deeper drafts and increasingly larger tonnage capacity, leading to a significant reduction in transport costs per ton. Larger vessels tend to call fewer ports and to select those with deeper maritime accesses, which is why water depth becomes an essential element for port performance in attracting larger vessels. Insufficient water depth in access channels is an important limitation for a port, attracting less competitive vessels, further aggravating transport costs, limiting the area of influence and negatively affecting port services. Hypothesis 4 was confirmed. Ports with better infrastructures obtain better operational results, directly and through shipping services and port size.

The results support the argument that the size of ships calling at a port, partly determined by existing maritime accesses, is an essential factor not only affecting the port's operational performance, but also the port's position in the global shipping hierarchy.

In other words, it was shown that the characteristics of the shipping services and vessels calling at the port determine the operational performance, as well as the fact that shippers choose ports in particular due to the type and level of shipping services provided, vessel size and frequency (Tongzon and Heng, 2005; Veldman and Bückmann, 2003).

Hypothesis 5 was therefore confirmed. Improved shipping services have a positive impact on a port's operational performance.

7 Conclusions

The study shows that different port operational performance is influenced by several characterisation factors which are essential when considering building a new port or adapting existing ones, as well as for the development of competition policies of both port and terminal, in order to achieve a more competitive port industry.

The results validated the assumptions and hypotheses proposed on the conceptual model, suggesting that it cannot be ignored as an explanatory tool of port performance and that the port characteristics have a decisive influence.

The study shows that the location of a port is a key variable for its operational performance, with direct and indirect effects through the mediating variables of infrastructure and size. The size of the port has a positive relationship with operational performance, although the maritime services have also relevant weight by acting as mediator of infrastructure and specialisation of the port, which also has direct effects on performance. We can say that to have greater performance, it is preferable to invest in larger ports rather than to create smaller ones, by locating them closer to regions with strong economies, with appropriate maritime accessibility, allowing the entry of large vessels. Specialisation of the port in general cargo also has a positive effect on performance.

7.1 Implications

These findings have significant implications for port management, specifically due to a better understanding of competitive conditions arising from the port characteristics effect on port performance and the evidence of the role of markets. A better knowledge of these questions by the port decision-makers results in a greater degree of rationality in investment decisions when contemplating building a new port or new terminals.

7.2 Avenues of future research

It would be important to define new variables that could better explain port performance and the role of mediating variables, as well as to test the relationships between constructs to test other more effective models, following the methodology adopted.

7.3 Strengths and limitations

A major limitation found was the size of the sample and lack of cooperation of port authorities. Literature about SEM suggests that sample size should be at least 100 for it to have significant goodness of fit (Breckler, 1990; Marsh et al., 1996). Nevertheless, Bentler and Chou (1987) allow as few as five cases per parameter and in this particular path analysis case, significant fit results were obtained. The main strength relies on the multitude of variables used and the diversity of European ports included in the sample.

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Annex 1

Table A1 Port's sample

	Port	*Country*
1	Aarhus	Denmark
2	Antwerp	Belgium
3	Bourgas	Bulgaria
4	Braila	Romania
5	Cadiz	Spain
6	Cardiff	UK
7	Cartagena	Spain
8	Castellon	Spain
9	Cherbourg	France
10	Coruña	Spain
11	Dover	UK
12	Dubrovnik	Croatia
13	Dunkirk	France
14	Galati	Romania
15	Gijon	Spain
16	Hamburg	Nederland
17	Hanko	Finland
18	Helsinki	Finland
19	Klaipeda	Lithuania
20	Koege	Denmark
21	Kokkola	Finland
22	Larochelle	France
23	Leixões	Portugal
24	Limessol	Cyprus
25	Lisbon	Portugal
26	Livorno	Italy
27	London	UK
28	Lübeck	Germany
29	Malmo	Sweden
30	Marseille	France
31	Patras	Greece
32	Ploce	Croatia
33	Riga	Latvia
34	Rouen	France
35	Savona	Italy
36	Setubal	Portugal
37	Shoreham	UK

Table A1 Port's sample (continued)

	Port	*Country*
38	Sines	Portugal
39	Stockholm	Sweden
40	Taranto	Italy
41	Tees and Hartlepool	UK
42	Tulcea	Romania
43	Valletta	Malta