PERFORMANCE ANALYSIS IN PORT CONTAINER TERMINALS

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Abstract – Sea transport offers a significant importance for the global modern economy, so an evaluation approach to ensure efficiency in the cargo flow should be studied and introduced, starting with sea ports. This paper serves as support for an efficiency and performance benchmarking analysis of 54 container terminals ports, distributed across 23 European countries, for the year 2013. The operating efficiency of a seaport is the critical element for its attractiveness in the international market. Among other methods, the Data Envelopment Analysis (DEA) was selected. The approach adopted has four inputs (quay cranes, terminal area, quay length and operational expenses) and an output (container throughput in TEUs). The final result evaluates three ports as efficient in DEA_{CCR} model and fourteen in DEA_{BCC} model. The size and returns to scale of the ports, the identification of reference ports and the evaluation of variables slacks are analyzed in detail. Finally, it is concluded that the efficiency of a port is usually related to the regions of Western and Southern Europe and to its capacity that a port focuses only on containers movement.

Keywords – Data Envelopment Analysis (DEA), Europe, Seaport, Benchmarking, Efficiency

1 INTRODUCTION

Sea transport has a significant importance for the global modern economy. Oliveira (2015) argues that the European Union remains the world's largest trading block. He also affirms the importance of ports and references the deep concern in connecting them to inland transportation network. This would ensure the cargo flow. Oliveira reinforces that a new approach, beyond the national logic, should be implemented to achieve major European projects which would help strengthen cohesion and in turn make a significant step in designing an important European transport network.

The shipping market is mainly composed of two players, the carriers and the seaports. The functions and characteristics operations of these two players are increasingly dependent on the diversity of commodities that require different types of transport. The range of the physical nature of the products leads to different ship designs, as well as different ways of handling those products. Therefore, the value, type, and the amount of product to be delivered and handled beyond the vessel and infrastructure requirements, determines the operation mode of transport and handling of goods. Caldeirinha (2015), President of APP, suggests that not all charges, merchandise, supply chains and products require the same kind of treatment.

According to the MEMO/13/448 of the European Commission of 23 May 2013, the various European ports exhibit variable performance levels, as exemplified by the Antwerp, Hamburg and Rotterdam ports which stand out in terms of size (moving a fifth of goods arriving by sea to Europe). The huge concern in making all ports efficient is the current inbalance of European ports, which cause enormous globally inefficiencies and reduce the competitiveness of Europe. In other words, this inefficiency leads to longer trips causing significant traffic deviation as well as sea and land routes more distant which consequently translate into more gas emissions, more congestion and higher business cost.

This study aims to understand which variables determine the port performance and to what extent each of them contribute to the overall level of service. The port performance evaluation is a complex task, not only due to the variables and diversity of operations that a port presents, but also by the ports diversity at the global and European level. This paper focuses on measuring the ports efficiency in Europe. However, other goals are revealed like the identification of the main methodologies used in port efficiency measurement, determining which are ports efficient and not efficient in Europe (considering the sample) through a benchmarking methodology, and a final evaluation of the results in order to realize which variables, internal and external to the model, influence the ports in terms of efficiency and what measures can be taken to make them more efficient. Specific objectives to compare efficiency levels between port groups will also be analyzed in the shape of size, administrative structure (private service port, landlord, toolport and public service port), geographical location (Central and Eastern Europe, Southern Europe, Western Europe and Northern Europe) and type of goods moved in a port.

The analysis took account information for the year 2013. This study was careful to collect data from only safe and reliable sources that contained accurate information, so that the final results were reliable and close to reality. To this end, the collection of the information was based on the port's reports and accounts, and also additional information, which was requested directly from the port authorities.

The paper structure is organized into five chapters. Although each of them presenting quite specific goals, section 1 starts with an introduction and specifies the main objective of this study. Section 2 outlines the bibliographic review. Section 3 describes the DEA methodology. In section 4 is present the case study, in particular, the definition of variables and data and the empirical analysis. Finally, the section 5 represents the conclusion on the research.

2 BIBLIOGRAPHIC REVIEW

In the last years, especially during the last two decades, several studies have been conducted to evaluate port efficiencies, applying the performance analysis methodology.

In this review we will focus on the DEA methodology, which will be detailed and applied further on. These studies are divided into two groups, first on the basis of the data analyzed and second as a function of their goals.

Regarding the analyzed data, the evaluation considers multiple years (panel data), as well as, data collected for a specific year (cross-sectional data). With respect to the main objectives of the previous studies, it is important to reference almost all of them; the core objective is essentially the evaluation of container port efficiency. On the other hand, in recent studies, namely Barros (2006), Barros, et al. (2007), Carvalho and Marques (2007), Nigra and Marques (2010) and Pjevcevic, et al. (2012), their focus is increasingly associated with the total port efficiency as a whole. Therefore, the recent studies introduce as output the multiple types of cargo throughput separately, and not only the number of TEUs of container throughput, which is the olden studies focus.

All the studies analyzed are briefly presented, in Appendix 1.

3 METHODOLOGY

3.1 Introduction

The production is defined as a process in which the inputs are identified, designed and transformed into outputs. The production unit that converts the resources into product is denominated as a decision making unit (DMU). Figure 1 outlines this process. Considering the limited resources available in any industry, it is essential to study the quality of production, including the efficient use of resources and the maximization of products. In this respect Wang, et al. (2005) argued that this issue led to a very important concept, the performance, which is used to describe the production quality.

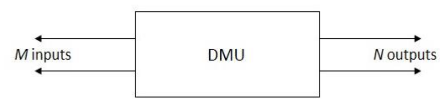

Figure 1 Production process (DMU)

The productivity and efficiency concepts gather large importance in the performance evaluation. Wang, et al. (2005) defined the productivity of a DMU as a ratio between the output and the input, and the efficiency as a relative concept which can only be assessed by a benchmarking or comparison process. The efficiency also includes the technical, scale and allocation efficiency.

Technical efficiency is defined as relative productivity at a certain time, space, or both. In an economic context, the production frontier and cost frontier characterize the technical efficiency, respectively as output-oriented and input-oriented. The production frontier reflects the current state of technology in a kind of industry. The scale efficiency relates to a discrepancy between the size of the current production with optimal production. The allocation efficiency focuses on the production costs taking into account the price information.

The performance evaluation is an essential tool for organization development. This aims to increase the system efficiency and can define a company behavior in its current state and in the future, in context of its objectives and the results obtained.

Figure 2 helps to analyze the input and output orientation for each approach (variable returns to scale and constant returns to scale, discussed in detail in section 3.2.), involving only one input and one output. The *f* curves represent the production frontier in a given time period for a specific activity, it is also known as the efficiency frontier. The technical efficiency is defined as the distance to the efficiency frontier (the points *B* and *D*, which represent DMUs, are technically efficient while the point *P*, also a DMU, is technically inefficient). For both situations, in figure 2(a) and 2(b), the productivity of the point *P* is measured by the *CP/C0* ratio, according to the definition of productivity. From the same amount of input (*C0*) it is possible to increase the output level, that is, achieve point *D*. The productivity increased and was converted into point *D*, becoming technically efficient, being equal to the *CD/C0* ratio.

In condition 2(a) the variable return to scale model is represented, described by the *f* function and a company operating at point *P*. The technical efficiency in output oriented model is equal to *CP/CD* ratio, while for the input oriented model it is *AB/AP*. In case 2(b) the model with constant return to scale is described, where *AB/AP* = *CP/CD* for any inefficient point (in this case point *P*).

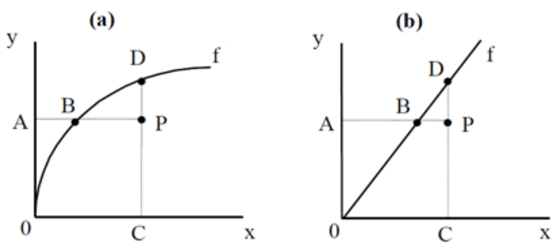

Figure 2 Example of constant and variable returns to scale (Coelli, 1996)

The economic efficiency involves the technique and allocation efficiency (reflects respectively the ability of a company to obtain the maximum output for a given set of inputs and the ability of a company to apply the inputs in optimal proportions, given their respective prices). For the following example were two considered inputs (x_1, x_2) for the same amount of output (y), as shown in figure 3. This takes the *f* curve as the technical efficiency frontier and the *c* line as the price ratio between the inputs. The *B'* point is technically efficient but inefficient in terms allocation, while the point *B* is inefficient for both. The allocation efficiency can be evaluated as *OB''/OB'*, while technical efficiency is evaluated by *OB'/OB*.

Introducing a dynamic perspective, the possibility production frontier tends to change over time, the change is related primarily to the impact of technological innovation in the industry. However, the pace of a company cannot keep up with the dynamic movement of the market. The figure 3 depicts two possibility frontiers in two different periods, the *f* and *f'* frontier, that belonging to the periods *T* and *T-1*, respectively. The DMUs that are in the frontier *f* achieve through the same number of outputs produced, spend less inputs, that is, these DMUs achieved to adapt to the dynamic market development. Those who remained in the frontier *f'* or were unable to invest properly or have not had possibilities to invest.

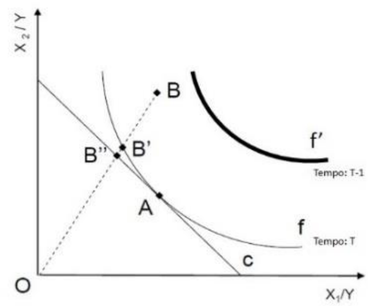

Figure 3 Technical and allocation efficiency (Carvalho and Marques, 2007)

In figure 4 the degree of inefficiency caused by the pure technical inefficiency or by the scale operational inefficiency is analyzed. The *f* curve exhibits the pure efficiency frontier and the point *A* presents an optimal operation scale. In a perspective with an input orientation, the point *B* presents two inefficiency types, the pure (Calculated as *OB'/OB* ratio, in figure 3) and scale (Calculated as *OB''/OB'* ratio, in figure 3) inefficiency.

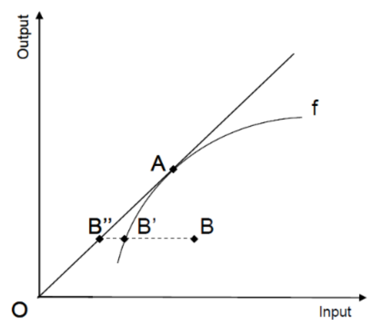

Figure 4 Scale and pure technical efficiency (Carvalho and Marques, 2007)

3.2 DEA Methodology

The Data Envelopment Analysis methodology has significantly developed becoming an influential tool in benchmarking analysis. This progression is justified by the ease of model utilization and the possibility of applying multiples inputs and outputs. This method has been widely used in many areas from health, education, banking, ports, among others (Lin and Tseng, 2005).

The theoretical development of DEA methodology began with the Edward Rhodes thesis for obtaining the doctoral degree, under supervision of W. W. Cooper, published in 1978. In that same document, Charnes, Cooper and Rhodes (1978) defined the DEA methodology as "A mathematical programming model applied to observational data provides a new way of obtaining empirical estimates of relations — such as the production functions and/or efficient production possibility surfaces that are a cornerstone of modern economics". The DEA is a non-parametric linear programming methodology that evaluates the relative technical efficiency of decision making units, represented in this study as being each port (more specifically the port area that involves the containers throughput). This methodology analyzes the optimal combinations between inputs and outputs, based on the observed performance of each DMU. These combinations form the efficiency boundary and determining the relative efficiency levels.

The DEA has two support approaches, shown in the example of figure 5. The CCR model (constant returns to scale) developed by Charnes, Cooper and Rhodes (1978), enables an objective assessment of global efficiency, identifies the sources of inefficiency and estimates the amounts of these inefficiencies, gives a global productivity measure and designates productive efficiency indicator based on constant returns to scale. In figure 5(a) a set of DMUs classified through DEA_{CCR} model, in which only the point *C* is considered efficient is shown. The BCC model (variable returns to scale), developed later by Banker, Charnes and Cooper in 1984, assumes that the evaluated decision making units present variable returns to scale, distinguishing between scale and technical efficiency. This model estimates the pure technical efficiency for a given scale of operations, and identifies present increasing, descending or constant returns to scale. In the condition 5(b) is exemplified the DEA_{BCC} model, herein, the *A*, *C* and *F* points are considered efficient. Coelli (1996) points out that the evaluation of the input and output oriented model provides only equivalent measures of technical efficiency when there is constant returns to scale, and the opposite it is variable when present variables returns to scale. The input oriented model calculates the amount of inputs that can be reduced while maintaining the outputs level produced, and the output oriented model, that keeps the level of consumed inputs, evaluates the quantity of outputs to increase (Carrasqueira, el al., 2010).

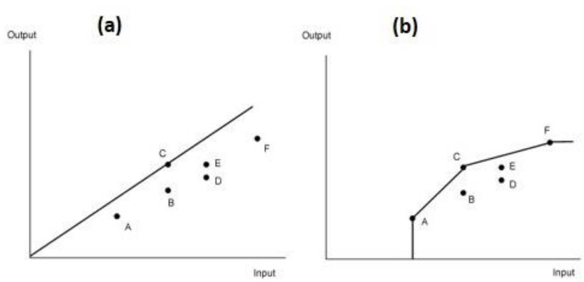

Figure 5 Production frontier example of DEA_{CCR} (a) and DEA_{BCC} (b) models (Kim and Harris, 2008)

The DEA methodology is rigorously detailed in the system of equations 1, 2 and 3 (DEA_{CCR} and DEA_{BCC}). Consider *n* DMUs, where each DMU (*j* = 1, 2, …, *n*) produces *s* outputs (*r* = 1, 2, …, *m*) through the consumption of *m* inputs (*i* = 1, 2, …, *m*). With regard to DEA_{CCR} approach, equations 1 and 2 describe it.

Max $$h_k = \frac{\sum_{r=1}^{s} U_r Y_{rk}}{\sum_{i=1}^{m} V_i X_{ik}}$$

Subject to: $$\frac{\sum_{r=1}^{s} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \leq 1 \qquad (1)$$

$U_r, V_i > 0$; *j* = 1, 2, …, *n*; *r* = 1, 2, …, *s*; *i* = 1, 2, …, *m*

Where: h_k is the relative efficiency of the respective "*k*" DMUs; Y_{rj} are the respective outputs "*r*" given each DMU "*j*"; X_{ij} are the respective inputs "*i*" given each DMU "*j*"; U_r is the weight of each output "*r*"; V_i is the weight of each input "*i*",

The formulation 1 is a linear programming problem which can be converted to respective dual model as indicated by formulation 2:

Min $$h_k = \theta - \varepsilon \left[\sum_{r=1}^{s} s_r^{+} + \sum_{i=1}^{m} s_i^{-}\right]$$

Subject to: $$\sum_{j=1}^{n} Z_j X_{ij} + s_i^{-} \leq \theta X_{ij}$$

$$\sum_{j=1}^{n} Z_j Y_{rj} - s_r^{+} \geq Y_{rj} \qquad (2)$$

$Z_j \geq 0;\ s_r^{+}, s_i^{-} \geq \varepsilon \geq 0;\ \forall\ i, r, j$

Where: ε is a small positive number; Z_j is the weight of a DMU "*j*"; s_r^{+} is the variable that belongs to the output slack; s_i^{-} is the variable that belongs to the input slack.

In the system of equations number 3 is described the DEA_{BCC} model. In this model is added a convexity restriction $(\sum_{j=1}^{n} Z_j = 1)$ to the previous formulation number 2. The dual model to DEA_{BCC} approach is then present as follows:

Min $$\theta - \varepsilon \left[\sum_{r=1}^{s} s_r^{+} + \sum_{r=1}^{m} s_i^{-}\right]$$

Subject to $$\sum_{j=1}^{n} Z_j X_{ij} + s_i^{-} \leq \theta X_{ij}$$

$$\sum_{j=1}^{n} Z_j Y_{rj} - s_r^{+} \geq Y_{rj}$$

$$\sum_{j=1}^{n} Z_j = 1 \qquad (3)$$

$Z_j, s_r^+, s_i^- \geq 0; \forall\, i, r, j;$ $r = 1, 2, \ldots, s$; $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$

4 CASE STUDY

4.1 Definition of Variables and Data

The sample contains fifty four ports, or DMUs, belonging to twenty two European countries (Belgium, Croatia, Denmark, England, Finland, France, Germany, Greece, Holland, Ireland, Italy, Latvia, Lithuania, Malta, Northern Ireland, Norway, Poland, Portugal, Russia, Slovenia, Spain, and Sweden). However, due to lack of information availability a higher number of ports was not possible to collect, even so, this sample is sufficient large, allowing a robust and consistent efficiency estimation for most of the analyzes made. This paper analyzes the port performance for the year of 2013, the sample evaluated has only one temporal dimension, referred to as cross-sectional data. The DEA methodology was the methodology selected and only the output orientation was used.

All the ports have different regulatory policies and management structures that make them differentiate and make this sample totally complete. In this sample does not exist any port considered as outlier, even so, the Rotterdam and Hamburg ports present atypical values, while not having been considered totally inconsistent, since, because the values are not far away from the boundary, which makes them become outliers, both ports have huge infrastructures toward to the rest of Europe, in other words, theoretically these values are completely consistent and framed.

The variable selection procedure in this study included several steps such as the environmental context in question, the purpose of the study, the data availability and the empirical literature support. Once adjusted and adapted the variable selection process, the inputs selected and introduced into the final model were the total number of quay cranes, terminal area, quay length and OPEX while the only output was the containers throughput. Table 1 describes the variable statistics.

However, there are other variable types, also very important, which will aim to support the result of the behavior justification and analyze what features out of the context can influence the terminal performance, known as external variables. These variables are intended to reflect the external environment and understand if there is any relation to the final result, always with the intention of try to find some rationale to justify or improve the terminal performance and that makes it even more productive. The selected external variables includes the diversification of the type of cargo moved in a port, the port management model and the geographical location of the port.

This study aims to evaluate the port performance through a consistent, standardized and reliable methodology. Based on these assumptions, only two models were used, the DEA_{CCR} and DEA_{BCC}, both with output orientation. This approach was chosen because the focus of this work is to maximize the number of containers throughput in TEUs, in a port, assuming a given level of inputs that will be necessary for the proper operational functioning of a port. Practically all ports in the sample are private nature with any state regulation (landlord model), which highlights the focus on results. Private entities prefer to perform huge and appropriate investments that may result in increased future income through the essential increase in the number of containers throughput. On the other hand, if a port is under public law, a more conservative attitude would be expected, that is, the focus of the study would be the minimization of the use of inputs and sequentially the model orientation would be the input orientation.

Table 1 Descriptive statistics of the variables

Variables	*Output*	*Inputs*			
	Container Throughput [TEU]	Total Number of Quay Cranes [Number]	Terminal Area [m²]	Quay Length [m]	*OPEX* [EUR]
Mean	1 615 580,67	15,41	969 685,19	2 175,28	26 972 015,60
Standard Error	326 193,09	2,98	183 774,33	386,46	6 141 961,23
Median	616 508,00	7,75	405 000,00	1 340,00	11 963 092,23
Standard Deviation	2 397 019,85	21,87	1 350 459,98	2 839,89	45 134 013,06
Minimum	30 243,00	2	74 000,00	320	533 950,57
Maximum	11 621 046,00	125	6 752 000,00	16 980,00	256 779 392,20
Sum	87 241 356,00	832	52 363 000,00	117 465,00	1 456 488 842,00
Count	54	54	54	54	54

The software used for efficiency calculation was the Efficiency Measurement System (EMS Ver. 1.3), developed by Professor Holger Scheel, University Dortmund (Scheel, 2000).

4.2 Empirical Analysis

The DEA_{CCR} model classified only three efficient ports in particular Vigo, Alicante and Malta Freeport. While DEA_{BCC} model highlights fourteen efficient ports, identified as the ports of Gavle, Norrkoping, Duisburg, Bremen Ports, Hamburg, Rotterdam, Antwerp, Marin, Vigo, Algeciras Bay, Alicante, Taranto, Malta Freeport and Ravenna. The mean and median are higher in DEA_{CCR} (the value 1 assigns to the maximum efficiency and the "infinite" value assigns to the "zero" efficiency, because the model that is applied is the output orientation). However, by DEA_{CCR} model, the results obtained sharing an information that are encompassed by pure technical and scale efficiency. On the other hand, DEA_{BCC} identifies only isolated technical efficiency. The empirical results illustration show that there is abundant waste in the port production in the sample. In the application of DEA_{CCR} theoretically waste is higher than in DEA_{BCC} because while the former has an average of 5,92, the latter has an average of 4,11. That is, hypothetically, the ports in this study can, on average, considerably increase their output levels by 5,92 or 4,11 times the current state while maintaining the same level of input to each of the models respectively. However, such occurrence is realistically impossible, since different market characteristics do not allow it, such as competition and market power between the various ports and shipping company, the influence from different countries to finance the projects, the power of import and export also varies substantially from region to region, among other characteristics that may directly or indirectly influence.

The Stockholm port presents in both models the high inefficiency value with 2366%. The three ports that recorded higher inefficiency were the ports of Ust-Luga, Bay of Cadiz and Stockholm. These ports besides to find in the top 5 with regard to the container throughput weaker, also require substantial resources to operate.

The two DEA models have a strong correlation as the results of Spearman's rank and Pearson correlation coefficients demonstrate, 0,75 and 0,86 respectively.

5 CONCLUSION

5.1 Conclusion Summary

In a period that has been witnessed an increase of competitiveness between ports, in order to face this kind of competitive environment, modern ports will have to adapt and take into account all factors, internal and external, that influence their performance. External factors include a demand variability understand of its customers and an assignment of a more importance to the marketing area and to the position of the ports within an international network managed by supply chain management. Internal factors consist in reducing waste for the same level of production, or in the increase of production for the same level of resources, to ensure sustainability and competitiveness.

Regarding to the slack analysis the variable with the highest slack for both models was the terminal area. Usually when a port is classified as inefficient, this independent variable which is in excess, must be appropriately reduced. In addition to the terminal area in both models, in DEA_{CCR} model, the OPEX also demonstrated a high slack, while in DEA_{BCC} model the quay length and OPEX arise also with a high level of wastage. For these variables that affect negatively, by excess, the port efficiency, in order to improve its overall performance, new measures to make these excess resources in income sources to the port must be implemented. The adoption of the ports efficient best practices is a more conservative alternative way which can be performed. Nevertheless others ideas may be applied as a rental space within the port area that is not being used, the labor remuneration has a variable component depending on the achievement of the stipulated objective, a better space organization either in the terminal area or on the quay length, the port's capacity to attract new shipping companies, among many others alternatives that may become a more competitive port.

In respect to the port production based on their size analysis, it was found that in DEA_{BCC} model for higher traffic levels (greater than 5.000.000 TEUs), higher are the number of efficient ports. Whereas in DEA_{CCR} model there is higher efficiency in ports when the container throughput number is between 1.000.000 and 2.999.999 TEUs. In this topic was concluded the higher the container throughput the higher the efficiency. All these values are based on a mathematical structure that characterizes each of the models, since the DEA_{BCC} materializes a convexity restriction, that is, while the DEA_{BCC} distinguish between technical and scale efficiency, and thus estimates the pure technical efficiency for a given operations scale, the DEA_{CCR} performs an assessment of the overall efficiency based on constant returns to scale, without distinguishing technical efficiency with scale, hampering the ports efficiency evaluation with the greatest volume of container throughput. The ports that have been most affected by the scale were the Norrkoping, Marin and Helsinki ports.

The port production was also analyzed in terms of economies of scale. The sample contains three types of returns to scale, the constant, decreasing and increasing returns of scale, respectively with the weights 7,41%, 62,96% and 29,63%. The study found that the decreasing returns to scale is closely related to the ports that have larger dimensions (more containers throughput). While the ports with constant and increasing returns to scale are usually those which present smaller dimensions (less containers throughput). In a theoretical context, ports classified as increasing returns to scale should increase their production in order to improve their efficient result, because in these circumstances the input required increased, so as to enhance the same level of output, is substantially less. By contrast, in the ports classified as decreasing returns to scale, they can improve their efficiency performance by inputs consumption reduction, thus reducing inputs will lead to a reduction in production that port, but at a rate that will increase the port efficiency.

Finally, with concern to the geographical location, in the DEA_{CCR} model the Southern Europe region is the one with best efficiency levels, however the Northern Europe region is where there are the worst levels. In DEA_{BCC} model, the ports of the Western European region, are those with higher efficiency levels, with an average efficiency 292%. While the Northern Europe region continues to present the results of more negative efficiency. Regarding to the type of cargo it was concluded that a port is more efficient when focusing on a certain type of goods, in this case, container throughput. For the administration model was unable to obtain the expected conclusion, since, there is a huge lack of consistency in the data because forty-four ports represent the landlord model, about 81% of the total sample. Beyond this discrepancy, none port has registered any public service model as characteristic. However, the only findings in spite of all these disadvantages, is that between the private service and toolport model, the latter seems to have better efficiency results compared to the first, and that in the landlord model, perhaps due to contain more than 81% of the sample is where almost of all efficient ports are.

5.2 Limitations

Availability data made difficult the development of the study. However, several alternatives have been implemented. In order to overcome the problem of slowed the implementation, in this case, the completion of the database, which is the essential support to the whole study. Nevertheless, some potential variables were not introduced in the model, since, or did not exist sufficient credible source to produce reasonable values, or there was no source and consecutively there was no data availability for all DMUs required.

It was verified that the availability of data and even some data of privacy is very dependent from region to region. The ports of the England, Scotland, Turkey, Romania and Bulgaria region did not provide any relevant information to be entered in the database, since they alleged that was confidential information and they were not allowed to share it. In other cases data availability was complicated, but through a more intense and detailed research, like direct communication (via e-mail and telephone) with particular facilities, among other methods, such as Google Maps, it was possible to achieve all the desired data with a good level of reliability.

The EMS software selection and the utilization of DEA efficiency analysis was also at the beginning an obstacle to combat, since initially many others software existed but each with some drawbacks like the limitation on the number of data to be used, others with a very complex installation and others only with payment. Fortunately, it was found the EMS software that fulfills all the requirements necessary for the implementation of this study.

5.3 Directions for Future work

The main goal of this study was to evaluate the European ports performance. However, for future work it would be very interesting the implementation of other variables, methods, approaches and contexts, and finally analyze the final results.

With regard to the variables, many others were not included due to lack of available information and because of the increase of complexity for the study. Employees number, CAPEX and cranes and tugs number grouped by functions and technology could be incorporated into the model in order to make the most realistic results. Another important feature is the level of technology that each port or terminal presents, because the management software used, the cranes and tugs may not match the same level of productivity (or technology) in all the analyzed ports, so a certain differentiation should be applied. Finally, although the sample had enough size to meet almost all of the issues, a higher volume of data, which in this study was not possible, ought to be implemented.

With respect to the methodology, other techniques could have been applied for later be compared with the finals results. Apart from the DEA, there is also the SFA methodology, a parametric model, which focuses on achieving results of relative efficiency through an efficiency frontier which is based on a probability distribution function. Although in this study has been applied the DEA methodology with output orientation, it could have also been used the input orientation, which is reserved for a future work. The use of a larger set of methodologies for the same sample could strengthen the results reliability.

To finish, others four approaches or contexts may be relevant for future studies. First, in relation to the supply chain, the cargo after leaving the port will have his next destination as warehouses or retailers and the conducting of a benchmarking analysis of different transport operations, at different levels at the chain, would be very interesting, in a way that it could be indirectly related to a continuation of this study. Second, in addition to the assessment of port efficiency, which was performed in this study, the running of a ranking for those ports and even grouping them by country and region would be also a case of relevant analysis. Third, very important, it would complement this study with the same sample but for a different set of years in order to obtain findings and growth dynamics over time, also called of panel data. Finally, the last approach, is still suggested an efficiency analysis in function of the CO_2 emission with the task to minimize the gas emissions and thus make this industry environmentally sustainable.

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APPENDIX 1 – DEA APPLICATION IN PREVIOUS STUDIES

Author	Data description	Type of methodology	*Input/Output* variables
Tongzon (2001)	16 ports (4 Australians, 12 internationals) (1996)	DEA-Additive and DEA_{CCR}	Input: number of cranes; number of container berths; number of tugs; terminal area; delay time; labor. Output: annual container throughput; ship working rate.
Wang, Song and Cullinane (2003)	57 terminals (included in top 30 international ports)[1] (2001)	DEA_{BCC}, DEA_{CCR} and FDH	Input: quay length; terminal area; quayside gantry; yard gantry; straddle carriers. Output: container throughput.
Lin and Tseng (2005)	27 international container ports distributed in 18 different regions (1999 – 2002).	DEA_{BCC}, DEA_{CCR} and SFA	Input: container gantry cranes; container quay length; stevedoring equipment; container yard. Output: container throughput.
Barros (2006)	24 Italian ports (2002 – 2003)	DEA_{BCC} and DEA_{CCR}	Input: number of employees; CAPEX; OPEX. Output: liquid bulk; dry bulk; number of vessels; number of passengers; number of containers with TEU; number of containers without TEU; total sales.
Cullinane, Wang, Song and Ji (2006)	57 terminals (included in top 30 international ports)[2] (2001)	DEA and SFA	Input: quay length; terminal area; quayside gantry; yard gantry; straddle carriers. Output: container throughput.
Wang and Cullinane (2006)	104 container terminals (29 European countries) (2003)	DEA_{BCC} and DEA_{CCR}	Input: terminal length; terminal area; equipment costs. Output: container throughput.
Barros, Al-Eraqi, Mustaffa and Khader (2007)	22 ports in the region of East Asia and Middle East (2000 – 2005)	DEA_{BCC} and DEA_{CCR}	Input: berth length; terminal area; distance nautical miles to port reference – Hong Kong. Output: ships call; cargo throughput (containers and liquid and dry bulks).
Carvalho and Marques (2007)	41 European ports in 11 countries (2005)	DEA_{BCC} and DEA_{CCR}	Input: OPEX; CAPEX. Output: throughput of dry bulk; liquid bulk; containers cargo; conventional general cargo; Ro-Ro; passengers.

[1] Except for the port *Tanjung Pelepas* in Malaysia and San Juan.

[2] Except for the port *Tanjung Pelepas* in Malaysia and San Juan.

Nigra and Marques (2010)	57 international ports (21 are Iberian ports) (2008)	DEA_{BCC} and DEA_{CCR}	Input: CAPEX; other operational costs; employees. Output: throughput of general cargo; solid bulks; liquid bulks; passengers.
Munisamy (2010)	69 container ports (17 Asian countries) (2007)	DEA_{BCC} and DEA_{CCR}	Input: berth length; terminal area; area for refrigerated containers; number of quayside cranes; total number of equipment within a terminal. Output: container throughput.
Pjevcevic, Radonjic, Hrle and Colic (2012)	5 ports (river Danube in Serbia) (2001-2008)	DEA	Input: total area of warehouses; quay length; number of cranes. Output: port throughput.
Lu and Wang (2012)	31 container terminals (14 China ports and 17 Korea ports) (2008)	DEA_{BCC}, DEA_{CCR} and DEA (super efficiency)	Input: yard area per berth, number of quayside cranes per berth, number of terminal cranes per berth, number of yard tractor per berth, berth length, water depth. Output: container throughput per berth.
Lu and Park (2013)	28 container terminals (belonging to 9 East Asian ports)	DEA_{CCR} and RA[3]	Input: berth length; size of yard areas; number of quay cranes; terminal cranes; yard tractors. Output: container throughput.
Munisamy and Jun (2013)	30 ports (Latin America, Central America, South America and the Caribbean regions) (2000 – 2008)	DEA_{BCC} and DEA_{CCR}	Input: berth length; terminal area; quay equipment; yard gantry; reach stackers; straddle carriers; forklifts; yard tractors. Output: container throughput.
Shin and Jeong (2013)	8 terminals (South Korea)[4] (2007 – 2010)	DEA_{BCC} and Directional Distance Function Model	Input: quay length; number of container cranes; container yard. Output: container throughput and CO_2 emission.
Mokhtar and Shah (2013)	6 container terminals (Malaysia) (2003 – 2010)	DEA_{BCC} and DEA_{CCR}	Input: terminal area; maximum draft; berth length; quay crane index; yard stacking index; vehicles; number of gates lanes. Output: container throughput.

[3] Regression Analysis.

[4] Belonging only two ports: *Busan* port and *Kwangyang* port.