Performance evaluation using data envelopment analysis: the case of GENERAL CARGO TERMINALS (December 2013)

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Abstract — This paper aims to assess the performance of the main Portuguese terminals that handle general cargo. The method adopted for the performance evaluation is the Data Envelopment Analysis (DEA) that compares the terminals between each other by benchmarking and determines the existent inefficiencies of the system. It was chosen to optimize the resources (infrastructures, equipment etc) in relation to the fixed yearly values of cargo throughput of each terminal. The variables were selected with the aid of the Compensatory Method of Single Standardization, which determines the variables to be used by an efficiency index. The results demonstrate that the terminals have different performance levels and different patterns of efficiency. These point to an improvement of certain facilities of the inefficient terminals. Next to this, some terminals have the conditions to operate in high levels of efficiency but when compared to bigger terminals they are considered to be actually inefficient. The results present the most efficient terminals, of this type of cargo, on the Portuguese ports, indicating points of attention that can improve the overall efficiency.

Index Terms — Break bulk cargo, DEA, General cargo terminals, Performance evaluation, Seaport industry.

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I. INTRODUCTION

Benchmarking is a popular instrument that is globally accepted as a tool to improve the performance and competitiveness of business organizations. The scope of applications varies from large corporations to small business companies, public and semi-public sectors and covers several types of industries [2][9][16][17]. Some authors denote benchmarking as a management tool that can be defined as the systematic process of searching for best practices, efficient and innovative ideas that lead to continuous improvement [18][21][4][5][10].

The competitiveness in the international market implies that each nation has good relations with other countries, skilled people, and appropriate infrastructures to meet their needs. Economic globalization has caused changes in the market, from production to consumption, inducing forced competitiveness throughout the chain.

The planning and management of all product movement, measuring costs, has become an essential condition in the dispute for the consumer market. Thus, cost reduction has become indispensable to the success of corporations in the global market condition. Cost reduction can be achieved by minimizing inefficiencies and by making a better use of the infrastructures. By optimizing the whole supply chain the country will be ranked on the international stage with a higher level of competitiveness. The transportation system, together with the correlative infrastructures, has proven to be crucial for satisfactory performance and market growth of the country. Ports are links of the transportation system and key elements for the interconnection with other nations. They are
considered privileged instruments of the external commerce once that ships are the mean of transportation that moves largest amounts of cargo per trip, [24]. International trade is closely connected to seaports, since almost all goods moving around the world are transported on ships and managed by ports. Thus, it is imperative to restructure the port sector, making it crucial to analyze and evaluate the performance of ports, to improve and expand the importance and development of a region or country.

Portugal presents the maritime modal as the mean of transportation with the highest values of exported cargo. By presenting features that highlight the country's maritime sector as the 943 km of border with the Atlantic Ocean and due to the economies of scale and low costs, Portugal can be considered a main entrance and exit of goods by shipment in Europe (Figure 1).

The analysis of seaports that handle break bulk cargo, common known as general cargo, is vital to the overall development of the sector. Therefore, inefficiency or gaps presented in the handling of the cargo could become a barrier to the development of the port, on national level.

The use of the DEA method to analyze and evaluate port terminals, is due to the different possibilities of analyzing the data that the method provides, a comparative analysis of efficiency of a set of units contained in the same sector of activities.

II. STATE OF THE ART

A. Seaport logistics

A seaport, for being a sub-system of the total transportation network and a venue of other means of transport, is essentially an economic infrastructure that serves to handle domestic and overseas cargoes. The increasing of transportation distances that are caused by the economical globalization implies, usually, the use of more complex transportation networks, modes and platforms. The loading, unloading, transshipment and preparation of cargoes are expensive and time-consuming operations, especially if they depend on transport systems that were not prepared for multimodal operations [14]. The internationalization of transportation provides significance to logistical requirements for intermodal transport of passenger and freight [14][20]. The replacement of the traditional heterogeneous maritime cargoes by homogeneous containers and the adoption of the container concept have created a revolution in ports which allowed maritime shipping to benefit from economies of scale not only in cargo handling but also in ship size [8].

Although the container is the most important development in the improvement of the multimodal concept of transportation in general and in seaports in particular [15], there is still a lot of cargo, such as oversized and heavy weight equipment, which has to be shipped break bulk. There is a lot of research done about containerized cargo but not so much about break bulk or the so called general cargo. The large economic growth of countries outside Europe, namely in East Asia [13][25], justifies the growing demand of cargo movements [14]. According to [12] seaport terminals are the physical connection between maritime transport, land transport and several components of the freight transport network. The terminal is therefore an important part of the chain, any increase in efficiency will contribute to the competitiveness of the full network [19][11][26]. [23] claims that the magnitude of the seaport

Fig. 1. Portugal privileged location in Europe.
infrastructure and connections to the predecessor and successor in the chain such as being linked to railways, contributes to the increase of the productivity of ports.

B. Performance evaluation

Performance of a system can be defined as the result of the combination of its elements. To evaluate a system in terms of its performance it is necessary to study the characteristics of the system and define the methods to be used. The performance evaluation of a company or organization is the way of measuring, based on one or more indicators, if the system is functioning effectively. By this the companies can assess if the adopted measures are having the contemplated effect and determine which following measures can be used to further improve the process. The basic objectives of a performance analysis are organizational management and control. These processes look for a balance of the system’s components, as for example managing the capacity in order to reduce waste. To analyze a seaport’s performance it is necessary to define the correct parameters that can monitor the performance and indicate methods to improve it. Standards have to be defined to allow a performance to be measured. This performance has to be observed from the perspective of the seaport administration and of its users.

Reference [1] says that benchmarking is more precise if the parameters defined for the seaport comparison are grouped in a selective way, e.g., according more specific characteristics. Studies that evaluate seaport performance intend to define and specify the various factors that can influence this performance and also its efficiency.

A seaport performance is affected by innumeros factors. Some of these factors are out of control of the authorities, as the economic level of the sector, the geographic location of the port, or the frequency of ships in transit [22]. There are at least two factors that ports can control directly, depending on their role on the waterfront: terminal efficiency and harbor fees. [22] supports the theory that a terminal’s efficiency is an essential component to any waterfront reform that pretends to improve a ports performance. This indicates that the efficiency of the terminals has a strong influence to all factors that determine a seaports performance, ensuring that the increase in efficiency of a terminal is a high priority in a general reform of a port.

C. Data Envelopment Analysis

Data Envelopment Analysis – DEA was developed by Charnes [6]. It is a linear programming based method defined to measure comparative efficiencies of entities called Decision Making Units (DMUs) These units use the same resources (inputs) and generate the same products (outputs). This technique results in a relative efficiency that counts the ratio between virtual inputs and outputs, in accordance with (1), where \( y_{ij} \) represents an output \( r \) of the unit \( j \). \( x_{ij} \) represents an input \( i \) of the unit \( j \). \( v_i \) and \( u_r \) represent, respectively, the weights of each input \( i \) and each output \( r \).

\[
\text{Efficiency}_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}
\]  

(1)

DEA is intended to measure and find inefficiency between DMUs. The DMUs adopted should have the same use of inputs and outputs, varying only in intensity. This collection should be homogeneous, e.g., should realize the same tasks with the same goals, work under the same market conditions and have an autonomy of making decisions. The selection of the relevant variables (inputs and outputs), for the evaluation of the relative efficiency of the DMUs, should be done according the problem to be analyzed, because the results of the analysis depend on the inputs and outputs selected.

There are two classic DEA models: CCR and BCC. The CCR model (also known as CRS or constant returns to scale) uses constant returns to scale as an hypothesis. The DEA CCR model
maximizes the ratio between the linear combination of outputs and the linear combination of inputs, with the restriction that for any DMU this ratio cannot be greater than 1. The BCC model, [3], or VRS (variable returns to scale), considers production efficiency cases with variable scale and does not assume proportionality between inputs and outputs.

From a non-mathematical point of view, BCC model indicates an efficient DMU as the one that makes better use of the available inputs, within the scale it operates. The CCR model shows an efficient DMU when the unit presents the best ratio of outputs in relation to inputs, e.g., makes better use of inputs without considering the scale of operation of the DMU.

These models can be oriented to optimize inputs, outputs or both. This orientation should be defined according the goals and conditions of the system to be analyzed. This method indicates, for each inefficient unit, subgroups of efficient units as a reference set.

In Figure 2, model CCR is illustrated. "A", "B", "C" and "D" are the DMUs analyzed. The DMU "B", because it is on the frontier, is considered efficient. The arrows indicate the projection of each inefficient DMU on the frontier through the reduction of resources (inputs), “AK”, “CM” and “DO”. This is required to make the DMU efficient.

Figure 3 shows the BCC model, oriented to inputs, in a graphical form. “A”, “B”, “C”, “D”, “E”, “F” and “G” are the analyzed DMUs. The DMUs “A”, “B”, “C” and “D”, are on the efficiency frontier and so considered efficient. DMUs “E”, “F” and “G” will need to reduce their inputs to be considered efficient.

![Graphical illustration of the input-oriented CCR model](image1)

III. PORTUGUESE PORT SECTOR

Ports can be defined as strong and complex entities that integrate various and multiple organizations and allow the docking and shelter of ships in a secure way. The port system is part of the transport system whose function is to move passengers and freight. According Collyer [7] the port is a national border for dynamic storage of goods, in which activities are carried out (customs, trade, health, tax, immigration etc.). It is a gate for great wealth, a supply source of offshore activities, a strategic point of the security of nations and, above all, the most important link in the logistics chain that supplies humanity.
In Portugal more than 50% of the goods imported and exported per year are done by maritime transportation. From 2010 to 2011 an increase of 2.8% for transport by sea was verified. Next to that, break bulk cargo increased 6.5% in the same period.

The DMUs chosen were these 11 terminals, that handle the majority of general cargo moved in the Portuguese ports. As some ports have more than one terminal and some of the terminals are under private companies concession, the DMU are going to be evaluated as independent units, and not connected to the port they belong.

### TABLE I

<table>
<thead>
<tr>
<th>Port</th>
<th>Terminal</th>
<th>DMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aveiro</td>
<td>Terminal Multipurpose North</td>
<td>DMU_01</td>
</tr>
<tr>
<td></td>
<td>Terminal Multipurpose South</td>
<td>DMU_02</td>
</tr>
<tr>
<td>Leixões</td>
<td>Dock 1 North</td>
<td>DMU_03</td>
</tr>
<tr>
<td></td>
<td>Dock 1 South</td>
<td>DMU_04</td>
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<td></td>
<td>Dock 2 North</td>
<td>DMU_05</td>
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<tr>
<td></td>
<td>Dock 2 South</td>
<td>DMU_06</td>
</tr>
<tr>
<td></td>
<td>Dock 4 North</td>
<td>DMU_07</td>
</tr>
<tr>
<td>Figueira da Foz</td>
<td>General Cargo Terminal</td>
<td>DMU_08</td>
</tr>
<tr>
<td>Setúbal</td>
<td>TERSADO</td>
<td>DMU_09</td>
</tr>
<tr>
<td></td>
<td>SADOPORT</td>
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<td></td>
<td>SECIL</td>
<td>DMU_11</td>
</tr>
</tbody>
</table>
A. Variables selection

The method used for the variable selection is called Compensation Method of Single Standardization. This is a two phase method based on scenarios. The first phase is the phase where the output is set out one to one with the inputs of all DMUs to select the one input that renders the maximum efficiency compared to the general output. In the second phase the average of all efficiencies is used to calculate the efficiency index for that particular scenario. The highest efficiency index is selected and this creates the best scenario that will be used for the performance evaluation of the terminals.

This process is repeated, but now the efficiency will be calculated by two inputs and one output. One of the inputs will be the one with the highest efficiency index of the previous step, the other will be filled by the remaining. The highest efficiency index will be selected again. This continues until all variables and combinations are analyzed. Due to the limited amount of initial variables, only three best scenarios where calculated. The selection process indicated above was done with both DEA models.

B. Results

The input-oriented DEA models were adopted to analyze the efficiency of the terminals. This means that the non-efficient DMUs are projected on the envelopment surface (efficient frontier) by reducing the discretionary inputs, and holding the outputs constant. Both the CCR and the BCC models were applied to the data with the aid of the software MaxDEA developed by Cheng Gang and Qian Zhenhua [27]. The version used is the MaxDEA 6.0 (Beta). The program has no limitation on the number of DMU to be considered and provides an easy human interface, thus allowing great flexibility in determining efficiency.

The efficiency evaluation was performed according the variables selected for each scenario of Table 3.

1) DEA CCR

For this approach the inputs used were the number of cranes, number of berths, storage area and as output the cargo throughput. Note that this method works with constant returns to scale, meaning that any variation on the inputs will result in a proportional variation of the output.

The following figures show the results of the analysis oriented towards the inputs with constant return, in a graphical form. Each graphic presents...
values of the efficiency index that goes from 0 (inefficient) to 1 (efficient).

In all three scenarios analyzed, SADORPORT was the most efficient DMU, already from the first case, where only two variables were used: number of cranes and cargo throughput. Which means that the addition of the other inputs, berths and storage area was not significantly relevant. On the other hand, Quay 2 South was the least efficient DMU in all scenarios studied. Despite of all differences in scores, all DMU presented an efficiency increase from scenario 2 to scenario 3, when the input storage area was added.

2) DEA BCC

The variables selected for this method were quay depth, number of berths, quay length and cargo throughput. With this approach the returns to scale are variable and so there is no proportionality between inputs and outputs. As the previous method, CCR, the results are presented in a graphical form with the efficiency scores going from 0 to 1.
The most efficient DMU, in all three cases studied for the BCC model, were TERSADO and General Cargo Terminal, and the most inefficient was the Multipurpose North. In this analyses scenario 2 presented the same efficiency scores as scenario 3 for all DMUs, which means that the addition of the last input, quay length, did not change the efficiency index of the terminals, having a weight equal to zero in almost all DMUs.

V. CONCLUSION

The DEA approach was performed on 11 terminals of the main Portuguese ports that handle break bulk cargo. The two classic DEA models, CCR and BCC, were applied and as result efficiency scores were calculated.

The CCR model indicated that from the 11 units analyzed, terminal SADOPORT, was the most efficient DMU, in all cases. The least efficient terminal the results presented was Dock 2 South. Although it presents facilities that allows the terminal to handle a great amount of cargo, when compared to the efficient DMUs as benchmark, it still does not operate sufficiently to make it efficient.

The same applies to the BCC model. Terminal multipurpose North obtained the lowest efficiency...
score when compared to terminals TERSADO and General Cargo, as the efficiency benchmarks.

The main points of inefficiency shown in this study were the infrastructures and the number of equipment (cranes). The increase of the quay depth of the terminal and the purchase of more productive equipment, would contribute to berth bigger ships that transport general cargo to increase the performance of the seaport.

For a higher quality performance evaluation, more data that defines the seaport operation, like processes, people and infrastructures could be included.

This method should be applied by seaport entities or other maritime organizations responsible for the national planning of the ports. Its use is important just by the fact that it indicates performance indexes of the relevant factors that form the port. This enables continues improvement systems and helps introducing necessary changes to increase the efficiency levels. The competitiveness of the entire logistical chain will increase and enables Portugal to become a bigger player on the international distribution market.

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REFERENCES


Software:

[27] MaxDEA 6.0 (Beta), Cheng Gang and Qian Zhenhua, DEA software, Copyright 2009-2013.