A comparative benchmarking analysis of main Iberian container terminals: a DEA approach

João C. Quaresma Dias*

CENTEC do Instituto Superior Técnico de Lisboa,
Instituto Superior de Engenharia de Lisboa, Portugal
E-mail: quaresma.dias@mar.ist.utl.pt
*Corresponding author

Susana Garrido Azevedo and João Ferreira

Management and Economics Department,
University of Beira Interior,
Pólo IV – Edifício Ernesto Cruz, 6200-209 Covilhã, Portugal
Fax: +351275319601
E-mail: sazevedo@ubi.pt
E-mail: jjmf@ubi.pt

Sérgio F. Palma

Departamento de Engenharia Mecânica,
Instituto Superior de Engenharia de Lisboa, Portugal
E-mail: sergio.palma@dem.isel.ipl.pt

Abstract: Benchmarking is an important tool to organisations to improve their productivity, product quality, process efficiency or services. From Benchmarking the organisations could compare their performance with competitors and identify their strengths and weaknesses.

This study intends to do a benchmarking analysis on the main Iberian Sea ports with a special focus on their container terminals efficiency. To attain this, the DEA (data envelopment analysis) is used since it is considered by several researchers as the most effective method to quantify a set of key performance indicators. In order to reach a more reliable diagnosis tool the DEA is used together with the data mining in comparing the sea ports operational data of container terminals during 2007.

Taking into account that sea ports are global logistics networks the performance evaluation is essential to an effective decision making in order to improve their efficiency and, therefore, their competitiveness.

Keywords: benchmarking; sea ports; data envelopment analysis; DEA; container terminals; efficiency; performance; shipping; logistics.

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Biographical notes: João Carlos Quaresma Dias (PhD in Strategic Management) is an Associate Professor in the Department of Mechanical Engineering at Instituto Superior de Engenharia de Lisboa (ISEL). He is currently the Head of Management Industrial Engineering and Maintenance Division and he lectures 'logistics and supply chain management'. He is a member of the Scientific Council (ISEL) and is also a Researcher in the (CENTEC) Centre for Marine Technology and Engineering (Seaports, Logistics and Transportation) in Technical University of Lisbon. He has a licence (MSc) in Mechanical Engineering from Instituto Superior Técnico and a BSc from Instituto Superior de Engenharia de Lisboa. He is the Chairman of the Board of Portuguese Logistics Certification. He has published books and scientific and technical articles. From 1993 to 1996 and from 2002 to 2005, he was a member of the Board of Directors of Seaports of Setúbal and Sesimbra Authority (APSS).

Susana Garrido Azevedo (PhD in Management) is an Assistant Professor of Logistics and Marketing at the University of Beira Interior (UBI) – Portugal. She is a Researcher of NECE – Research Unit in Science Business. Her research interests include logistics, seaports competitiveness and supply chain management. She has published in several journals such as: *The Service Industries Journal*, *Romanian Journal for Economic Forecasting*, *International Journal of Logistics and Transport*, *ICFAI Journal of Managerial Economics*, *Problems and Perspectives in Management*, *Journal of Operations and Quantitative Management*, *The Journal of Business & Retail Management Research*, among others, and she has published books in operations management, logistics and competitiveness areas.

João M. Ferreira (PhD in Management) is an Assistant Professor of Management at the University of Beira Interior (UBI) – Portugal. He is a Researcher of NECE – Research Unit in Science Business. His research interests include strategy, competitiveness and entrepreneurship. He is an Associate Editor of *Journal of Geography and Planning Regional* and a member of editorial board of some international journals. He is also the Editor of the *Economics and Strategic Management of the New Economics Papers* (*Econpapers*). He has published in a range of international journals.

Sérgio F. Palma (MsC in Mechanical Engineering) is an Instructor (Assistant Professor) in the Department of Mechanical Engineering at Instituto Superior de Engenharia de Lisboa (ISEL). He assists the curricular unit of Computer Aided Conception and Manufacturing and also maintains the network infrastructure of the department. He has a licence, BSc, from Instituto Superior de Engenharia de Lisboa. He is strongly motivated to continue his short experience in research, more specifically in transports and logistics. He has worked between 1996 and 2002 in several companies where he developed competencies in process engineering, information technology and information services and management.

1 Introduction

Benchmarking is generally associated to quality excellence since several researchers use the Deming PDCA cycle approach (NPC, 1999; Lee, 2002; Chan et al., 2006; Ribeiro and Cabral, 2006; Deros, 2006). Benchmarking is a popular instrument which is used universally as a tool to improve organisations' performance and competitiveness in business life (Wong and Wong, 2008). Its scope of application ranges from large firms to small businesses, public as well as semi-public sectors and encompassed various types of industries (Ball, 2000; Davis, 1998; Jones, 1999; McAdam and Kelly, 2002).

Some authors (McNair and Leibfried, 1992; Spendolini, 1992; Bhutta and Faizul, 1999; Bogan and Callahan, 2001; Deros, 2006) denote benchmarking as a management tool that can be defined as the systematic process of searching for best practices, innovative ideas and efficiencies that lead to continuous improvement. Benchmarking has been considered not only as a systematic process for evaluating the products, services and work processes of organisations that are recognised as representing best practices but also as a continuous improvement philosophy (Talluri and Sarkis, 2001). From a simple concept, benchmarking has undergone an evolutionary approach towards more sophisticated forms. Ahmed and Rafiq (1998) present different generations of benchmarking:

1 reverse benchmarking
2 competitive benchmarking
3 process benchmarking
4 strategic benchmarking
5 global benchmarking
6 competence benchmarking or bench-learning
7 network benchmarking which is occurring in this century.

Depending on the objectives and areas of benchmarking application a set of models could be identified associated with it. We can find the Deming PDCA cycle model (Chan et al., 2006; Ribeiro and Cabral, 2006), the SCOR model (Theeranuphattana and Tang, 2008), and the DEA model (Wong and Wong, 2008; Doyle and Green, 1994). According to Wong and Wong (2008), DEA is justified to be used as a benchmarking tool because of its features and inherent characteristics such as:

1 It is a robust, standardised and transparent methodology.
2 It is an effective tool for evaluating the relative efficiency of peer DMUs (decision making units) when multiple performance measures present.
3 It evaluates efficiency without the need to specify the relationships or tradeoffs among the performance measures prior to the computation.
4 It utilises the concept of efficient frontier as a measure for performance evaluation.

While there is extensive literature on benchmarking applied to a wide variety of economic areas, the scarcity with regard to sea ports bears testimony to the fact that this is a relatively under-researched area (Barros, 2005). In this context, and according to Barros and Athanassiou (2004), the benchmarking of European sea ports should be a priority on the research agenda since, despite the clearly non-homogeneous nature of European sea ports, they perform the same task and thus, used to benchmarking purposes (Tongzon, 2001; Barros and Athanassiou, 2004).

The complexity scenery that has been created by the present global logistic networks associated to the phenomena of financial uncertainty, as well as the economic growth of geographic zones far from Europe puts emphasis on the importance of the Iberian logistics management in operational terms. According to the global networks, the individual performance of container terminals will affect directly all the chains' functioning (Marlow and Casaca, 2003). The terminals impedance (Hesse and Rodrigue, 2004) must be small in order to maximise the added value generated within them and to improve their attractiveness in business terms.

Within an enlarged management context, measurement is the last process of a back-fed system of continuous improvement and supports the decision making process with critical information. In the past, measurement process was mostly endogenous, while the new trends appeals to a comparison between the competitors results. The benchmarking concept includes not only an internal analysis but also an external comparison, in which the performance indicators are established and valued. This relative comparison creates the necessity to change the internal processes. Some managers adapt competitive processes to their businesses in order to reach a product cost reduction and an increasing on competitiveness. This phenomenon is considered as coopetition (Song, 2003; Dias, 2006).

Historically, the sea ports operations are closed business activities, with scarce, vague and imprecise information. In the last years, there has been a growth in the TEUs handled and so, the terminal operations management should take into account their performance in a systematic and objective way. This scenario has been changing, and Soppé et al. (2009) presented the changes in the relationship between shipping lines (SL) and terminal operators (TO), which whore rivalry and are changing to cooperation. The world biggest terminals have been investing in the information technologies and systems directed to the customer and it is expected an increase in the number of services and available information. This open strategy, not only reinforces the terminals market position, but also within a global logistics view, giving them a critical capacity and importance in maintaining wealth in their geographic areas. The performance measurement of the main Iberian container terminals presented in this study intends to establish key performance indicators of the above mentioned terminals and to value them during 2007.

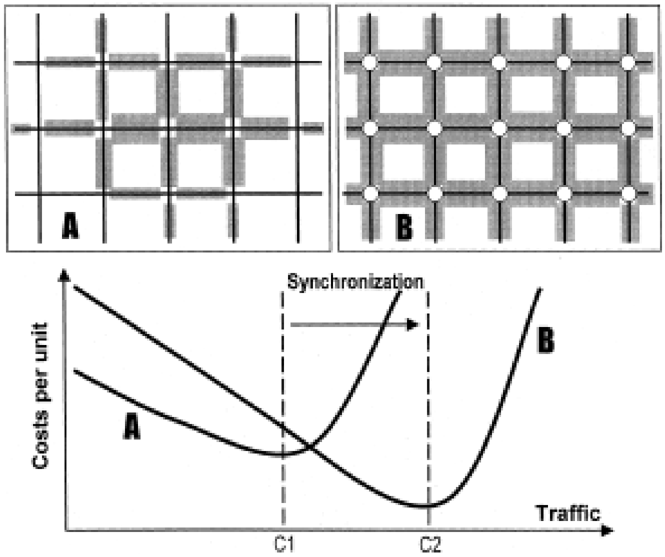
The research is structured as follows: next to this introduction, comes the review of literature on the importance, indicators and the performance measurement process of the selected terminals. In the third section, the research methodology is presented by proposing the objectives, characterisation of the sample, the data collecting and the measurement of the variables. In the fourth section, the results of the research work are presented as well as the results recursive analysis with the application of DEA method. Finally, the results are discussed, the conclusions are drawn and a future research proposed.

2 Sea ports logistics performance

Globalisation is possible thanks to the improvements made on transportation means, which have played a significant role in enlarging the number of products consumed by companies. If we consider that the technological improvements were not fundamental to a real reduction of the lead time' transportation, we will understand that the efficiency in transhipment is mostly achieved in the intermodal terminals (Rodrigue, 1999).

Though the studies concerning the supply network management did not analyse them carefully and nor the researchers have made any efforts to come up with new models to a better understanding of the used processes (Janelle, 1991). It can be said that a change is occurring specially in the last few years within this context. The movement of goods is occurring mainly by maritime transport not only because it is cheaper but also by geographic reasons. Nowadays, sea ports have many specialised areas related to the cargo movement, and they tend to a normalisation since of scale economies. The large economic growth of countries outside Europe justifies the growing demand of container cargo, taking its own advantages out of the concept of package modularisation, by a space-time compression and of the scale effect. As it is referred by Dowd and Leschine (1990), the container terminals are the physical connection between the ocean and the several modes of land transportation and the biggest component in the containerisation systems.

Figure 1 Transportation costs per unit; networks A and B



Source: Rodrigue (1999)

Table 1 Logistics friction

Impedance factor	*Assessment measures*
Transport/logistics costs	Distance, time, composition, transhipment, decomposition
Supply chain	Number of suppliers, number of distribution centres, number of parts/variety of components
Transactional environment	Competition, (sub-)contracting, inter-firm relationships, power issues, (de-)regulation
Physical environment	Infrastructure supply, road bottlenecks and congestion, urban density, urban adjustments

Source: Hesse and Rodrigue (2004)

As previously mentioned, the terminals play an important role in the efficiency of the supply networks. According to Hesse and Rodrigue (2004) the impedance concept or the sum of the frictional costs (Dias et al., 2008) caused by logistics processes and physical flows, must be observed through four different points of view: the traditional transportation/logistics costs, the supply chain organisation, the transactional and also the physical environments in which the distribution is made. In Table 1 we can see the relation between these four impedance factors and the assessment measures being minimised in each one of them.

Summing up, the sea ports operations should be considered as impedance factors directly connected to the physical environment. The systemic nature of logistics does not allow management to overlook the other three aspects as they will affect the terminal performances. The optimisation should be supported by economic analysis and trade-offs (Dias, 2006) aiming to achieve a good value between traffic and investment as it happens with the decoupling point of the value chains. Figure 1 shows this balance and establishes a relation with the dimension of the network that we aim to optimise.

2.1 Sea port performance indicators

In the 1976s United Nations Conference on Trade and Development (UNCTAD) published a document about the port performance indicators was written and since then it is seen by the researchers in this area as a reference (UNCTAD, 1976). In this document there are several types of indicators to evaluate the operational and financial performance. The evolution of the concept of logistics, in which the operators are classified according to its position in the supply chains and designated as transport service providers (TSP), allows us to understand that the measurement of the efficiency level of this entities is not confined to quantitative aspects and proves that qualitative indicators are necessary (Antão et al., 2005). However, the scope of this study is more reduced and it focuses on containers' movement within a terminal, in what is known as 'handling'. Hence, and according to a set of studies in this area (Roll and Hayuth, 1993; Tongzon, 2001; Turner et al., 2004; Cullinane et al., 2004), the measurement indicators in this study are enclosed in six inputs and two outputs of terminal containers performance for the year 2007 (Table 2).

Table 2 Performance indicators used

Performance Indicator	*Type*	
Number of cranes [Un.]	Input	E1
Number of employees [Un.]	Input	E2
Terminal area [ha]	Input	E3
Number of trailers [Un.]	Input	E4
Yard equipments [Un.]	Input	E5
Terminal length [m]	Input	E6
TEU moved [Un.]	Output	S1
Containers movement by hour by ship [Un.]	Output	S2

The description of these inputs and outputs used are:

- *Number of cranes* – it refers to the operations and depending on the amount of cranes it is possible to operate more ships and faster.
- *Number of employees* – it is related to the efficiency of the yard, since employees are needed to develop any operation at the terminal.
- *Terminal area* – it refers to the efficiency of the yard considering that the bigger the area the more containers it can stack. This input is measured in hectares and it refers only to the area dedicated to storage in the terminal.
- *Number of trailer* – it refers to the efficiency of the terminals since it will influence the operations developed in it.
- *Yard equipment* – it refers to the efficiency of the yard, as the quantity of equipment may influence the speed of operations. Yard equipment is any machine used to move containers at the terminals (reach stackers, transtainers, and straddle carriers).
- *Terminal length* – it represents the quay length of the terminals.
- *TEU moved* – this represents the quantity of 20-feet containers moved (if the container is 40 feet, it is counted as two 20-feet containers).
- *Containers movement by hour by ship* – it represents the number of terminal moves per hour per ship. This output is directly related to the speed of operations, that is, the faster a terminal handles a ship, the more efficient this terminal will be.

2.2 Sea ports data analysis

The performance measurement studies in containers' terminal are made according to two types of approaches: stochastic frontier analysis (SFA) and data envelopment analysis (DEA). Both present advantages and weaknesses, however the DEA applied under certain conditions shows more strength (Cullinane et al., 2006). The comparative studies developed by Barr (2004) present several solutions to the data processing. The DEA-SAED application, besides being free, assures low simulation times and uses the dynamic link library (DLL) technology. To perform a SOM analysis of the DMUs inputs it was used the SOM toolbox which is an implementation of SOM in the MatLab 5 computer environment (Vesanto et al., 2000).

3 Main Iberian container terminals

The organisational model of the Iberian Sea ports is almost the same, that is, the State owns the management rights of these areas and gives the power to the sea ports authorities to organise and develop them. Having in mind the surrounding environment, the port authority assigns the exploitation of certain zones to the private sector. The circulation of goods depends on the global economy and the sea ports gain or lose their importance within the logistics global networks mainly due to their geographic location and corresponding hinterlands (Dias, 2005). Usually, their relevance is measure by the cargo throughput, either in weight or in TEUs, which means that the area included by the port's activity has an economical-financial critical mass able to generate goods flows enough to make the sea ports business to look attractive. These differences lead to the classification of the sea ports as hub's or feeder's (Dias, 2005) that are destined for short sea shipping (SSS) and/or long sea shipping (LSS), with the capacity to make transhipment their intermodal infrastructures. The scenery studied by Gaspar (2001) presents the distribution of the gravity influence of seven Iberian sea ports, and the statistics referring to 2007 allow us to conclude that the scenery has not been altered, with the exception of the growth in the demand of containers movement. Figure 2 presents the movements of containers in 2007, expressed in thousands of TEUs, and to sea ports that show a handled above 100,000 TEUs.

Considering that in the Iberian Peninsula there are 12 container terminals that move annually more than 100,000 TEUs, the sample in this study is constituted by ten terminals which it is representative of the total population. In this sense, the Iberian container terminals focused on this study are the ones presented in Table 3.

Figure 2 Moved cargo in the main Iberian sea ports during 2007

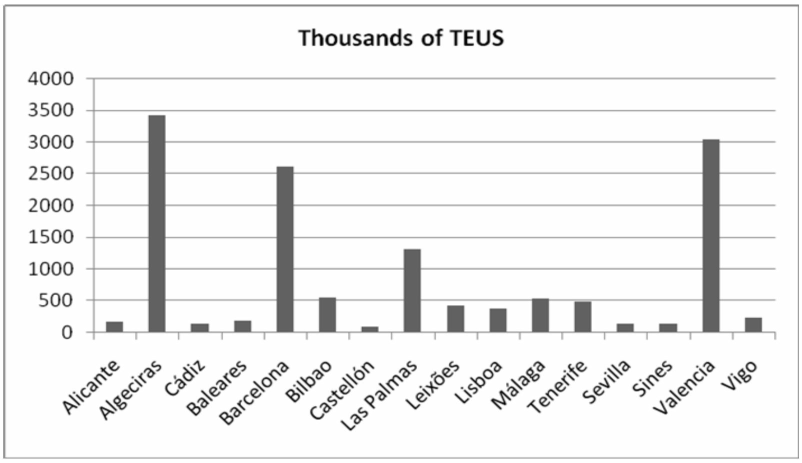


Table 3 Performance measurement of used terminals

Sea port	*Container Terminals*	
Bahia de Algeciras	Terminal 2000; Isla Verde	DMU 1
Barcelona	TCBCN; Catalunia	DMU 2
Valência	Principe Felipe; Levante	DMU 3
Bilbao	Santurtzi-Zierbena A1; Santurtzi-Zierbena A2	DMU 4
Vigo	Terminal Guixar	DMU 5
Alicante	Terminal de Alicante	DMU 6
Lisboa	TC Alcantara	DMU 7
Leixões	TC Leixões – Sul;	DMU 8
Leixões	TC Leixões – Norte	DMU 9
Sines	Terminal XXI	DMU 10

Table 4 Data collected in the research

	E1	*E3*	*E5*	*E6*	*S1*
DMU 1	17	86.6	39	2,970	3,420,533
DMU 2	21	93.29	107	2,484	2,610,100
DMU 3	27	158	157	3,600	3,042,665
DMU 4	15	46.7	18	1,527	554,558
DMU 5	3	18	7	769	244,065
DMU 6	2	6.8	15	354	172,729
DMU 7	3	12	16	630	329,000
DMU 8	3	16	15	540	272,045
DMU 9	2	6	5	360	160,316
DMU 10	3	36.4	3	380	150,038

3.1 Data Collection

In the data collection, the web sites of several entities were consulted, namely: sea ports, terminals, assigned companies (dealers), stowage companies, European Sea Ports Organization (ESPO), INE (Portuguese National Institute of Statistics) and Eurostat. The data gathering was made between the 18th and the 21st of November 2008.

The data collection is shown in Table 4.

3.2 The recursive analysis to the DEA method

The DEA method proposed by Charnes et al. (1978) is developed from an application of the linear programming that transforms multiple inputs and outputs into a relative efficiency index between the compared DMUs. The most used models are: the CCR model (Charnes et al., 1978) that takes into account continuous scale returns. Banker et al. (1984) introduced the BCC model, that allowing the production technology to exhibit increasing returns-to-scale (IRS) and decreasing returns-to-scale (DRS) as well as the constant returns to scale CRS. In analysing sea ports' efficiency the BCC model is the most appropriated (Sharma and Yu, 2008).

In this sense this model will be applied to solve the dual problem shown below.

$$\Theta^* = \min \Theta,$$

Subject to

$$\sum_{j=1}^{n} x_{ij}\lambda_j \le \Theta\, x_{io}, \quad i = 1, 2, \ldots, m;$$

$$\sum_{j=1}^{n} y_{ij}\lambda_j \ge y_{ro}, \quad r = 1, 2, \ldots, s;$$

$$\lambda_j \ge 0, \quad j = 1, 2, \ldots, n.$$

where:

Θ is the efficiency score

λs are the dual variables.

Based on the dual problem, a test DMU is inefficient if a composite DMU (linear combination of units in the set) can be identified which utilises less input than the test DMU while maintaining at least the same output levels.

According to Sharma and Yu (2008), DEA models are also classified as radial input oriented, radial output oriented or additive (both inputs and outputs are optimised) based on the direction of projection of the inefficient unit into the frontier. The application of DEA models may be orientated by input or by output or by both. The orientation by input minimises the entrances to the necessary level that allows a desired low level of exits. The orientation by output aims to maximise the exits to a fixed level of entrances. The orientation for both aims the biggest efficiency, minimising the entrances and maximising the exits. In this study the radial output oriented models is used.

The classic DEA method has some obstacles as referred by Doyle and Green (1994), and to overcome them Sharma and Yu (2008), use a recursive method applied to the first set of results as described by Zhu (2003), and the algorithm is as follows:

Define $J^I = \left\{DMU_j, j = 1, 2 \ldots, n\right\}$ to be the original, complete set of all *n* DMUs and interactively define $J^{I+1} = J^I - E^I$ where $E^I = \{DMU_k$ Î$J^1 | DMU_k$ has a DEA efficiency score of 1}. The steps of the algorithm for identifying multiple efficient frontiers are as follows, where *l* is the number of samples sets.

Step 1 Set *l* = 1. Evaluate the entire set of DMUs, J^1, to obtain the set, E^1, of the first-level frontier DMUs (i.e. when *l* = 1, the procedure runs a complete envelopment model on all *n* DMUs and E^1 consists of all DMUs on the resulting overall efficient frontier).

Step 2 Exclude the frontier DMUs from future DEA runs and set $J^{I+1} = J^I - E^I$.

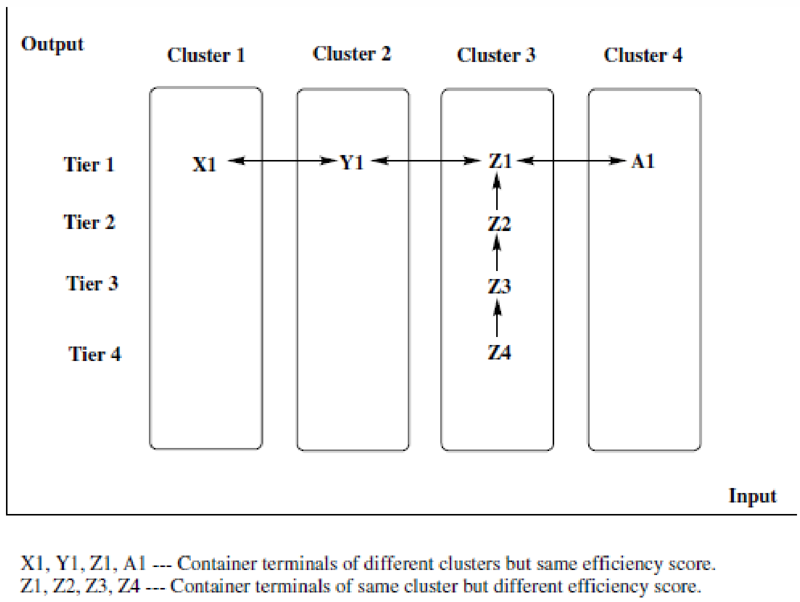
Step 3 If $J^{I+1} = 0$, then stop. Otherwise, evaluate the remaining subset of 'inefficient' DMUs, J^{I+1} to obtain the new best-practice frontier E^{I+1}.

Step 4 Let *l* = *l* + *1* and go to Step 2.

After this, the original dataset is segmented into *l* levels of relative efficiency, which will be the tiers on Figure 3. At last, it will be applied the Kohonen's self-organising map (KSOM) (Kohonen, 1982) to the original dataset, and will return clusters based upon their input characteristics. The research framework used is based in the one presented by Sharma and Yu (2008). The result will be an improvement path to the 'inefficient' terminals which leads them to the best practices of 'efficient' terminals.

In Figure 3 the improvement projection from the lowest tier to the upper most tiers of each cluster is illustrated. The application of the model reveals some interesting insight for improving poorly performing terminals. This approach is used in this study.

Figure 3 Terminals stratification after KSOM application



Source: Sharma and Yu (2008)

3.3 Data analysis

In the results after the first efficiency measurement by the DEA method, and before applying the KSOM algorithm, we can observe that four terminals present index 1 (Terminal XXI, Alicante, TC Leixões – N and Algeciras), that is, they are efficient. The other six terminals present lower efficient levels and should be deeper evaluated using other methods in order to allow some more conclusions. Figure 4 shows the results of the analysis oriented towards the exit, with variable return, under a graphic form.

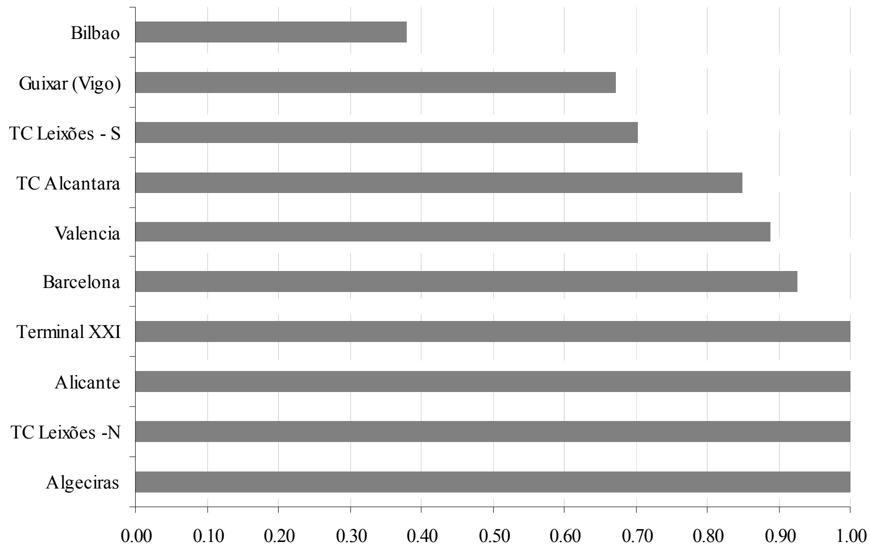
The regressive analysis of the DEA method using the algorithm presented in Section 3.2 returns the following levels:

Tier 1 Algeciras, Leixões Norte, Alicante and Terminal XXI (Sines)

Tier 2 Barcelona, Valência, Alcântara, Leixões Sul, Guixar (Vigo) and Bilbao.

As DEA allows the identification of the most efficient container terminals (Tier 2), managers are able to expand or adjust organisational practices from this group of container terminals, considered benchmarks, and employ these practices in the improvement of inefficient ones. It is important to highlight that DEA is a mathematical technique – derived from selected inputs and output. It is the managers' task to use the analysis as a support in decision-making, adopting best practices that will contribute to become container terminals more efficient.

Figure 4 Efficient level of the container terminals



The SOM application to the original dataset has provided the following cluster scenarios:

Cluster 1 Valência

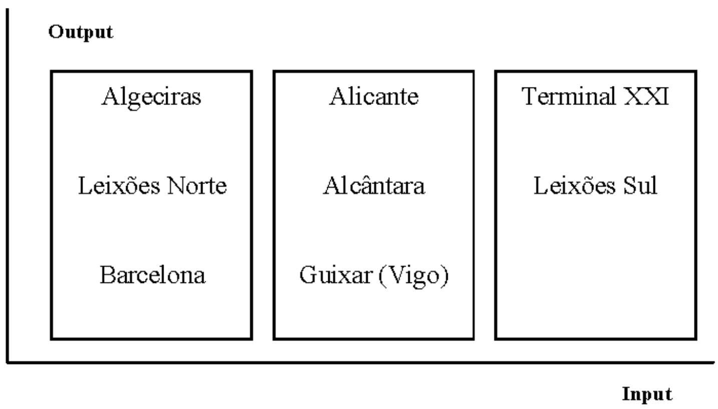
Cluster 2 Algeciras, Leixões Norte, Barcelona

Cluster 3 Alicante, Alcântara, Guixar (Vigo), Bilbao

Cluster 4 Terminal XXI, Leixões Sul.

So, we propose the following improvement path to the analysed terminals (Figure 5).

Figure 5 New rearrangement of container terminals



It was expected to have a 2 tier by 4 cluster arrangement. The proposed improvement path diagram intends to absorb the following inconsistencies: The second tier has two terminals which do not have a top terminal in its cluster. As the first cluster has only one terminal, it was decided to group cluster one and two. So, instead of four clusters we propose three. Inside the clusters, the terminal order is easily understood taking a closer look to Figure 4.

4 Conclusions

This study used the DEA model to analyse the performance of the main Iberian container terminals in terms of their efficiency. To attain this, a set of inputs and outputs related with these terminals was collected and a benchmarking analysis was developed since a comparative approach was made. Variables considered in this research include number of cranes, number of employees, terminal area, number of trailers, number of yard equipments, terminal length, TEUs moved and containers movement by hour by ship.

The general conclusion is that the majority of the container terminals studied are efficient however with different levels of performance. The Iberian container terminals with higher levels of efficiency are the Terminal XXI, Alicante, TC Leixões – N and Algeciras. The Bilbao container terminal shows the lower level of efficiency. These conclusions are relevant for policy-makers, for the ports authorities and for researchers. We urge the intervenient organisations, especially the sea ports and logistics authorities, the assigned companies, the navigation agents, the forwarders and others to include in their recommendations, the inclusion of a set of performance indicators to each terminal, to be defined, so that they can inform the intervenient partners of the value networks about their performance levels. Those who own high levels of service quality want to be recognised by the market and those who have not yet achieved that goal should make an effort to improve in order to gain competiveness. From a Benchmarking perspective, sea ports authorities after have recognised its strengths and weaknesses should to identify and to adopt the best practices used by sea ports with most efficient container terminals in order to improve its performance.

The results presented themselves biased fundamentally due to the low number of entrances and exits (they do not represent the port operations), data validity and extrapolation of entrance values. In spite of the sea ports investment in information technologies improvements, the data available in organisations web sites is not enough, it is not trustworthy and it is not presented in a standard way. Also, and ideally, more than one single year of observations should be used to provide a more representative basis for this comparative study of terminal containers. Nevertheless, due to the unavailability of data for other years and terminals, the study had to rely on one single year.

So, in the future and as further research we suggest that this study may be extended with an inquiry to the people in charge of each terminal operations, aiming to validate the collected data and also considering more years of analyse.

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