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In this paper the efficiency and performance is evaluated for 22 seaports in the region of East Africa and the Middle East*. The aim of our study is to compare seaports situated on the maritime trade road between the East and the West. These are considered as middle-distance ports at which goods from Europe and Far East/Australia can be exchanged and transhipped to all countries in the Middle East and East Africa. All these seaports are regional coasters, and dhow trade was built on these locations, leading this part of the world to become an important trade centre. Data was collected for 6 years (2000-2005) and a non-parametric linear programming method, DEA (Data Envelopment Analysis) is applied. The ultimate goal of our study is: 1) to estimate the performance levels of the ports under consideration. This will help in proposing solutions for better performance and developing future plans. 2) to select optimum transhipment locations.*

KEYWORDS

Middle East and East African Seaports, Data Envelopment Analysis, Seaports Efficiency, Performance measurement of Containers Ports, transsphipment.

1. Introduction

The transport and communications sector experienced growth fuelled by the increase in sea and air traffic volumes of cargo and passengers. The important and competitive maritime transport services benefit the economy of any region as a whole, since more than 80 percent of the world trade volume is carried by ships; maritime transport is thus an efficiency facilitator of the world trade, (Haralambides et al. 2001).

This role has become more apparent and crucial in today's expanded and diversified world trade system. Maritime transport was, and currently is, the backbone of development for many countries, (Cullinane et al. 2002). It related the knowledge of the old era with the newest knowledge of the modern world. Water transportation played a key role in human life since ancient times when mankind inspired with instinct developed different devices in this domain starting with piloting boats manually and ending with the use of mechanical power. The privilege of sea transport is the speed, comfort, safety and the possibility and ability to handle heavy traffic of goods and passengers at low prices. The present research analyses technical efficiency of Middle East and East African seaports with a DEA- Data envelopment procedure. The contribution of the present research for seaport economics is based in the analysis of seaports, not previously analysed and on the use of the distance between seaports as input in the production function adopted.

The motivation for the present research is the following: First, through the years, the operations in ports become complex more and more, the new technology impose new requirements in the infrastructure and materials handling. The fast development in the port industry, construction of large containers vessels, which need advanced handling equipment to manipulate the containers easily from/to the ship and other equipment's which transport from the terminal to the stack, and form stack to ship. Therefore, efficiency is a main issue in seaport management, (Tonzon, et al. 2005). Second, the movement of steamboats, ship, and goods in ports of diverse and multiple tasks is subject to the concept of modelling a large set of events which occur concurrently and simultaneously in the occurrence and correlation, like the movement of steamboats in the anchorage, loading/unloading of their goods, handling, stacking and performance of their desired services. Through dividing the port in terms of the allocation of terminals, mechanisms, and stores, the process of determining the locations for steamboats according to their qualities has been done, taking into consideration the level of accuracy and details, in that they would be suitable for simulation, and policies plans to manage asset so that for us to obtain results identical with the real situation, therefore the identification of strategically management inputs and outputs is of paramount importance to make a meaningful efficiency analysis, (Rios and Maçada, 2006). Finally, the paper focus on Arabian and African seaports, that have attracted the attention of the research so far and includes distance as an input to analyse such network industry.

The present paper is organised as follows: In the second section presents the contextual setting. In the third section the literature survey is presented. In the fourth section the methodology is displayed. In section 5 the data is presented. In section 6 the results are presented and finally in section 7 the conclusion and discussion is presented.

2 Contextual Setting

Over the past few decades, port industry witnessed remarkable development in many countries, particularly in East Africa (such as Sudan, Eritrea, Djibouti, Kenya and Tanzania) and the Middle East region (especially Saudi Arabia, Yemen, Oman, the United Arab Emirates and Iran). These countries possess ports of critical geographic locations on the international maritime trade route between the East and the West Figure 1. These ports are considered as middle distance ports at which goods carried from Europe and the far East/Australia and vice versa can be exchanged and transhipped to all countries in the Middle East, the Red Sea and East Africa. Since old times these ports provided services for the regional coasters and with time developed to rank among the important maritime international trade centres in the region. The strategic/geographic location of some of these ports encouraged modern container vessels to make short duration calls upon them for the interchange of goods e.g. shipping lines operating along Asia/Europe route, Asia/Mediterranean route and Asia/US East Coast route. Many studies dealing with ports efficiency have been carried out but were limited to ports of the European counties, Trujillo and Tovar (2007) and Asian seaports, Cullinane, song and Wang (2005). In this paper we try to highlight this side of the world which is: 1) considered as middle of the cord, linking the East and West sides of the world through the maritime routes, 2) Presently the region witnessing economic development in varies domains, 3) The ports under study (same of them) distinguish with a good infrastructure and equipment to be a transhipment ports, 4) The introduction of new variable, never used before, distance variable in ports efficiency. The seaport analysed are displayed in table 1.

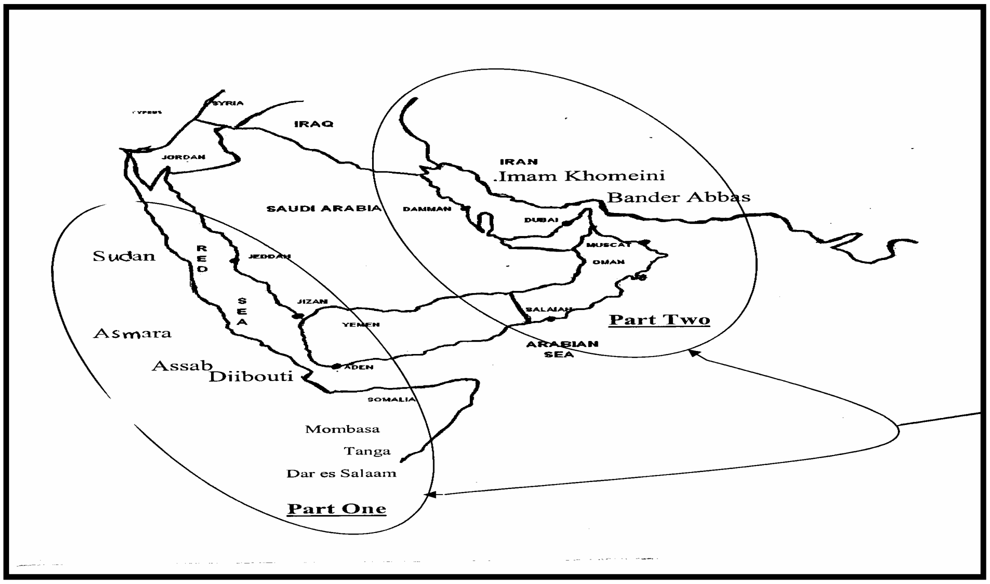

Figure 1: Map of Region

Table 1: Characteristics of Seaports of the Region

Country	Port	Ship calls	Cargo throughput	Terminal area
Arabian seaports				
Kuwait	Kuwait	3147.5	16106155.3	1586458
Saudi	Damman	2781.5	16210109.16	1843720
Saudi	Jubail	1461.5	8556475.667	1438800
Iran	Bander Abbas	3916.333333	12971234.67	2209000
Emirates	Dubai	6352.333333	66541267.83	1948610
Emirates	Khor Fakkan Sharjah	2049.333333	36292704	50000
Emirates	Khalid Sharjah	1506.166667	1367404.167	341292
Oman	Mascut	1635.833333	3836839.667	538898
Oman	Salalah	1653	19874564	1032692
Yemen	Mukalla	397.6666667	1239633.167	250567
Yemen	Aden	2462.666667	10306778.33	665140
Yemen	Hodeida	2042.166667	10458971.67	1200000
Saudi	Jeddah	4364.666667	39245363.33	2500000
Saudi	Yanbu	1466	10720699	727000
Sudan	Sudan	2430.833333	5536540.167	540253
African seaports				
Eritrea	Asmara	1601.833333	1509421.833	204057
Eritrea	Assab	818.5	535736	275319
Djibouti	Djibouti	2164.666667	6290891.667	151200
Kenya	Mombasa	3008.333333	13643213.83	114117
Tanzania	Tanga	194.5	334189	20000

Country	Port	Ship calls	Cargo throughput	Terminal area
Tanzania	Mtwara	173.6666667	276681.1667	400000
Tanzania	Dar es Salaam	1614.5	6232654.333	46864

3. Literature Survey

There is extensive literature on DEA, applied to a wide diversity of economic field in particular in seaports transportation. Cullinane et al. (2005) used DEA to emerge the major objective of port privatisation to improve the efficiency of this sector, with assumption the container throughput as output and area and length terminal, quay crane, yard crane, straddle as input. They concluded that public and private/public ports perform better than public/private and private. Hidekazu (2002) open a window in applied DEA to increasing import cargo and growing the number of container ship size in eight major international container ports using data for period between 1990 and 1999. Song and Cullinane (2001) apply ratio analysis to Asian container separates. Among the papers using DEA are Roll and Hayuth (1993), who present a theoretical exposition and propose the use of cross-sectional data from financial reports in order to render the DEA approach operational. The author observed that the ports whose already redeveloped can receive large-sized container vessels and increase the their throughputs. Poitras et al. (1996) limited the performance and efficiency only in handling containerized cargo across selected ports in term of geographical location, and data availability. Coto-Millan et al. (2000) applied a stochastic frontier model to evaluate the efficiency of 27 Spanish ports, Using the number of twenty foot container equivalent units handled per berth hour, and total number of containers handled per year as inputs. The efficiency results obtained depend on the type of DEA model employed, which depends on assumption made about returns to scales properties of the port production function. Tongzon (2001) applied DEA model CCR to provide an efficiency measurement for four Australian and 12 other international container ports for the year 1996.The output measures used are the total number of containers loaded and unloaded, and ship working rate. To produce the previous output, he introduced a variety of inputs as land, labor and capital which detailed in port equipments. The study has demonstrated that DEA provides a viable method of evaluating relative port efficiency. Cullinane, Song and Gray (2002), analyzed the administrative and ownership structure to estimate a Cobb-Douglas production function for major Asian container terminals. The relative inefficiency of these ports estimate using cross-sectional and panel data version. And Cullinane and Song (2003) whose estimate a production function increasing for Korean container terminals in case the privatization policies, chosen the stochastic frontier model as justified methodology and applied to cross-sectional data. Valentine (2002) focus on the selected ports of North America and Europe attempt to comparing efficiency, they assume that there are many factors to evaluate the port performance as the location, infrastructure, and connectivity to other ports. The Data used for 1998 constitute of number of containers, total throughput, total length of berth and container berth length. They concluded that DEA is useful to testing the container port efficiency and highlight the characteristics of an efficient port. The main aim to emerge that the measure of efficiency concern an individuals are not particularly highly correlated the department level DEA efficiency score. Wang (2003) analyzed the container terminal port efficiency using two alternative techniques DEA model CCR, BCC and FDH Model. They applied methods on the top of 30 container ports in the world in 2001, using throughput as output and quay length, area, quay crane, yard crane and straddle carrier as inputs. Lee Chee (2005) deal with treat tackles study on Malaysian container port industry with cross sectional of year 2003 as well as panel data over the years 2000 to 2003, compared to Singapore port, the Malaysian container port on average is sufficient to support the market demand. Table 2 show a summary of papers using different methods in ports efficiency.

4. Data Envelopment Analysis

Charnes et al (1978) were the first to introduce the DEA as a multi-factor productivity   analysis module for measuring the relative efficiencies of a homogenous set of decision making units (DMUs). The DEA-technique requires a large number of medium-sized linear programming problems to be solved. In particular, when DEA-analysis is performed interactively, the problems have to be solved rapidly while the decision maker is waiting. The principle of this non parametric method is based on two important sets of multiple variables called inputs and outputs variables (this will be discuses later).The efficiency score is the ratio of the presence of multiple input and output factors, it is defined by:

$$Efficiency = \frac{\sum weighted\ of\ outputs}{\sum weighted\ of\ inputs}$$

Adjusted to be a number between 0 and 1, e.g. the less inputs consumed and the more outputs produced, result for more efficient in a DMU. The ratio assumes that there are n

DMUs, each with m inputs and s outputs, the relative efficiency score of DMUp is obtained by solving the following model proposed by Charnes et al. (1978):

$$\max \frac{\sum_{k=1}^{s} u_k \, y_{kp}}{\sum_{j=1}^{m} v_i \, x_{ip}} \qquad (1)$$

$$\text{S.t.} \frac{\sum_{k=1}^{s} u_k \, y_{ki}}{\sum_{j=1}^{m} v_j \, x_{ji}} \leq 1 \; \forall i, \;\; and \;\; u_k \, v_j \geq 0 \;\; \forall k, j \qquad (2)$$

Where k=1 to s;

j=i to m, 1, and j=I to n.

y_{ki} =amount of output k produced by DMUi,

x_{ji} =amount of input j utilized by DMUi,

u_k =weight given to output k,

v_j =weight given to input j.

The constraints mean that the ratio should not exceed 1 for every DMU, the objective is to obtain weight u_k and v_j that maximise the ratio of DMUi, the DMU being evaluated. The computation of the above equations can be easily converted to a linear programming form as in LP (3)-(5) following:

$$\max \sum_{k=1}^{s} u_k \, y_{kp} = \theta_p \qquad (3)$$

$$\text{Subject to} \sum_{j=1}^{m} v_j \, y_{jp} = 1 \qquad (4)$$

$$\sum_{k=1}^{s} u_k y_{ki} - \sum_{j=1}^{m} v_j x_{ji} \leq 0 \;\; \forall i, \; u_k, v_j \geq 0 \;\; \forall k, j. \qquad (5)$$

The above iteration is run n times; the weight of u_k and v_j under the constraint of DMUp can identifying the relative efficiency scores of all DMUs greater than one. The values of θp in (3) are the performance score of DMUp relative to all DMUs between zero and one. The optimal objective value is for equation (4), the values of input and output must be nonzero and positive (5) unless the result are not significant. In general, a

DMU is considered to be efficient if it obtains a score of 1 and a score of less than 1 implies that it is inefficient. The ϕ_k and λ_j are dual variables and ϕ_k is a optimal value for the performance score of DMU_k and λ_j is the weight concern the DMUj use to produce the value of DMU_k.

The combination of the two model result as follow:

CCR Model Max ϕ_k

$$s.t.\quad \sum_{j=1}^{n} \lambda_j x_{ij} \le \phi_k \; x_{ik} \qquad i=1, 2\ldots m; \qquad (6)$$

$$\sum_{j=1}^{n} \lambda_j \; y_{rj} \ge y_{rk} \qquad r=1,2,\ldots,s; \qquad (7)$$

$$\lambda_j \ge 0 \qquad \forall\; j\,.$$

BCC Model

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad (8)$$

Through the equations of BCC model we see that all λj are now restricted to summing to one, given by convexity constraint.

The output- oriented measure of technical efficiency of k-p DMU is:

$$TE_k=1/\sum_{k=1}^{s} u_k \; y_{k\,i} \qquad (9)$$

The technical efficiency is concluded from DEA-CCR and DEA-BCC models as following [Wiliam et al.2000]:

$$SE=U_{CCR} \,/\, U_{BCC} \qquad (10)$$

equation (10) used to measure the score efficiency of DMU_k, if $SE_k=1$ then the score is efficiency otherwise the score is inefficiency if $SE_k<1$.

5. Data and variables

The application of DEA requires a number of units to perform the efficiency score; these units take the form of inputs and outputs. Selection of necessary inputs and outputs to carry out efficiency study is of particular importance, because these units will be the basis on which the efficiency is assessed. In general an input constitutes of any resource based use to produce outputs and outputs are any product or services produced by the resources units or a measure of how efficiency is affected. There are some restraints on which the inputs and outputs must be respected, The numbers of the resources for inputs is equal or greater than the number of outputs; it is preferable to use a limited number of units in order to ensure effective discrimination between the units. The values used must be positive for both, the resources and product selected must have same degree of importance and the inputs can be designed as controlled or uncontrolled. Inputs and outputs can be anything, including qualitative measurements.

Therefore, DEA is a multi-criterial approach, capable of manipulating multiple inputs and outputs which are expressed in different measurement units. Any statistical method can not perform this type of analysis. In general DEA focuses on the number of observations repeated of the events through the resources surroundings. To estimate the suitable location of the ports under study, we used data for the years 2000-2005; the ports considered in analysis are listed below Table 3:

Table 3: Characteristics of the Variables.

	Inputs			Outputs	
	Berth Length (m)	Terminal Area (m2)	Distance Nautical Miles	Ships Call	Cargo throughput Tons
Mean	3641.111111	931075.7222	2493.098889	4931.166667	14383096.23
Std. Error of Mean	633.8984882	187203.9037	312.1813132	286.1191791	3697265.529
Median	2344.5	696070	2106.995	5085	10571431.96
Mode	1140	46864	818.5	312	542167.97
Std. Deviation	2689.403518	794238.8986	1324.473141	1213.900871	15686169.16
Variance	7232891.281	6.30815E+11	1754229.101	1473555.324	2.46056E+14
Skewness	1.647501389	0.679014677	1.6349636	-3.53979762	2.545995732
Std. Error of Skewness	0.536277899	0.536277899	0.536277899	0.536277899	0.536277899
Kurtosis	2.734498708	-0.846064429	3.231012816	14.05668125	7.302345401
Std. Error of Kurtosis	1.037795083	1.037795083	1.037795083	1.037795083	1.037795083
Range	10060	2453136	5533.83	5571	65999099.84
Minimum	1140	46864	818.5	312	542167.97
Maximum	11200	2500000	6352.33	5883	66541267.81
Sum	65540	16759363	44875.78	88761	258895732.1
Count	18	18	18	18	18

These ports accounting for better movement of freight in the region and the owners' asset of handling equipments at same time. The data was obtained from the annual statistics reports of some ports authorities, by fax and Email and through internet (using Google Earth and ports web site as Maritimechain.com and Ports Harbours Marines Worldwide). The measurement of output is indicated for two elements 1) Ships and 2) movement of general cargo (dry and liquids, containers) unload and load. The measurement of the inputs is considered by the indicators: Total berth length, storage area and distance from Hong Kong port of each port in the region (an average point in the east).

The number of DMUs (n) is greater than the combined number of inputs and outputs (m+s), the selection of input and output elements is crucial for successful application of DEA and ensured the convention above (18>(2+4)) [William et al.2000]. The software Frontier Analyst from Banxia software was applied to solve the DEA models. There are two models on the return to scale of ports production function, called CCR model (constant return to scale) and BCC model (variable return to scale). In DEA-CCR model all observed production combinations can be scaled up or down proportionally, and in DEA-BCC model the variables allow return to scale and is graphically represented by a piecewise linear convex frontier [Cullinane et al. 2006]. In this paper we propose the input-oriented and output-oriented DEA models seeking maximization of output while the given current inputs remaining same. The technical efficiencies derived from the DEA-CCR and DEA-BCC models are frequently used to obtain a measure of scale for DMU, given by SE=UCCR / UBCC [William et al.2000].

The efficiency of any port depends crucially on security port system, services provided, easy entrance, labour skill, storage capacity and equipment.

The cargo throughput and ships call variables are important indicators of any port production considered as outputs. The resources of the port are constituted by the total berth length and terminal area. The distance used in our models is considered as an average distance of the all ports in the east, because the distance varies from each port in the east into the destination port in the region. There is an advantage of short distance to reduce the cost of ship. The is calculated by taken the distance of each i port in the list from Japan, Hong Kong, Singapore and Australia (reference ports in East) using www.maritimechain.com, the average distance Xi is calculated from the previous four distance.

Suppose that X_{1i}, X_{2i}, X_{3i}, X_{4i} are the distance from the above four ports, the average distance is calculated dividing the four distances by 4, according to the formula:

$$X_i = \sum_{1}^{4} Xji \Big/ 4 \qquad \text{for } i= 1 \text{ to } 22.$$

6. Results

We applied DEA to analyse the efficiency score of the ports, using the software Frontier Analyst with two models namely DEA-CCR and DEA-BCC. Among the 22 ports considered in this study, DEA is carried on 18 ports of highest productivity Table 1. Table 3 represents the efficiency estimates, the scale efficiency and scale type of each port. The score report show that three and six ports out 18 are efficient under DEA-CCR and DEA-BCC models. Comparing the result of two models, the BCC show more efficient ports than CCR as indexed with average value of 0.69 and 0.77 for each model, because CCR model provides information in scale and technical efficiency together, while BCC model measures pure technical efficiency only Table 4.

The output oriented applied in this paper to select the ports specific in term of distance, equipment and sophisticated management Theatrically, the output of technical efficiency is given by $TE_k=1/U_k$ for k term of DMU, then the ports under study must increase their product on average to 1.5 times for the same inputs. The scale properties of ports production show four constant returns to scale, most of ports increasing returns to scale accepted two decreasing returns to scale.

Table 4: The relative efficiency of seaports using DEA-CCR and DEA- BCC models

Country Port	DEA - CCR	DEA - BCC	Scale Efficiency	Return to scale
Khor Fakkan Sharjah	1	1	1	Constant
Mombasa Kenya	1	1	1	Constant
Dubai Emirates	1	1	1	Constant
Djibouti	0.8644	0.9184	0.94120209	Decreasing
Aden Yemen	0.8521	0.8588	0.99219842	Constant
Hodeida	0.846	0.8591	0.98475148	Constant
Dar es Salaam Tanzania	0.8405	1	0.8405	Decreasing
Sudan	0.7498	0.7693	0.97465228	Constant
Mascut Oman	0.6395	0.6681	0.95719204	Constant
Salalah Oman	0.6395	1	0.6395	Decreasing
Bander Abbas Iran	0.6244	0.8061	0.77459372	Constant
Kuwait	0.5855	0.5875	0.99659574	Constant
Jeddah Saudi	0.5848	0.6871	0.85111338	Increasing
Yanbu Saudi	0.5101	0.5278	0.96646457	Constant
Khalid Sharjah	0.4733	0.5357	0.88351689	Increasing
Assab Eritrea	0.466	1	0.466	Decreasing
Damman Saudi	0.4502	0.4515	0.99712071	Constant
Jubail Saudi	0.2701	0.271	0.99667897	Constant
	0.688677778	0.77446667	0.90344891	

The inefficiency assumed for CRS and VRS is due to decline in the numbers of ships call which cause the decreasing of throughput. In general the global result is sufficient for the majority of ports except for Salalah port in Oman and Assab in Eritrea cause of the weak attribution on the ships call which affect in the throughput and this weakness is remarked on all the inefficiency ports appearing in the Table 4 using both model CCR and BCC.

The study show that the majority of ships arrival is accumulated on the ports which have a short distance, also we noted that the berth length does not influence so much on ships call. On the other side the load/unload is accumulated on ports whose have berth length of 1000m to 3000m and have a short distance.

The contribution in general appears heavily on ships call and distance variables for the scores ports, whereas the contribution appear as following: Khor Fakkan 0 %, 98%, Monbassa 100%, 93%, and Dubai 100%, 7%, in spite of little distance between the region ports.

7. Discussion and Conclusion

The aim of this paper was to evaluate the efficiency in ports situated in the Middle East and East Africa. DEA analysis allows determining the relative efficiency of the above ports. First the majority of ports must improve the level of their outputs up to 1.5 times keeping the same inputs. Regarding to the items (quantity) of inputs and outputs, we note that the improvement of the inefficient ports due to less of number of ships call and throughput. The analysis shows that three ports are currently working efficiently; two are localized in the Arabian Gulf Dubai and Khor Fakkan and the one in east Africa Mombasa at Kenya. Regarding to inputs and output variables of the ports, the approach location, big equipment, capacity of berthing and storage are the important input factors. The contributions for the three efficient ports as following: 1) Berth length constitutes of 93% for Dubai and for the others 0%. 2) Ships call contribution constitutes of 100% Mombasa, 0% Khor Fakkan and 100% for Dubai, and 3) Distance contribution constitutes of 98% for Khor Fakkan, 93% for Mombassa and 7% for Dubai. In general we concluded that the big length of the berth does not impact on the ships arrival i.e. the increase in ships call in these ports is possible without causing any congestion problem.

These two indicators Berth length and Ships call play an important rule for waiting time and congestion in the ports, for avoid these problems using the distance factor to select the suitable transhipment ports (hub) which have suitable location and high performance. Finally an investment of the public and private sector will help seriously to participate to develop and expand the inefficient ports in the region, and suggest to ships lines to create a policy to encourage ships to load/unload in these ports. More investigation is needed to clarify unsettled questions.

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9. References

Agostino G. Bruzzone, Pietro, G. Roberto R (1999). Operative Requirements and Advances for the New Generation Simulators in Multimodal Container Terminals. Winter Simulation Conference.

A. Imai, E. Nishimura, and S. Papadimitriou. Berth allocation with service priority. Transportation Research Part B, 37:437-457, 2001.

Andrea E. Rizzoli, Nicoletta Fornara, Luca Maria Gmbardella (2002). A simulation tool for combined rail/road transport in intermodal terminals. Mathematics and Computers in Simulation. 59(1-3): pp. 57-71.

Asperen, E. Van, R. Dekker, M. Polman, H. de Swaan Arons, and L. Waltman. (2003b). Arrival Processes for Vessels in a Port Simulation. ERIM Report Series Research in Management, ERS-2003-067-LIS.

Banker R. D., Chang H. (1995). A simulation study of hypothesis tests for differences in efficiencies. International Journal of Production Economics 39(1-2): pp. 37-54.

Banker R. D., Hsihui Chang, William W. Cooper (2004). A simulation study of DEA and parametric frontier models in the presence of heteroscedasticity. European Journal of Operational Research 153: pp. 624-640.

Barros Carlos Pestana. (2006). A Benchmark Analysis of Italian Seaports Using Data Envelopment Analysis. Maritime Economics & Logistics 8: pp. 347-365.

Barros Carlos Pestana & Manolis Ahanassious. (2004). Efficiency in European Seaports with DEA: Evidence from Greece and Portugal. Maritime Economics & Logistics 6: pp. 122-140.

Barros, C.P. (2003a) Incentive Regulation and Efficiency of Portuguese Port Authorities. Maritime Economics & Logistics 5(1): pp 55-69.

Barros, C.P. (2003b). The Measurement of Efficiency of Portuguese Seaport Authorities with DEA. International Journal of Transport Economics 30(3): pp. 335-354.

Barros, C.P. (2005) Decomposing Growth in Portuguese Seaports: A Frontier Cost Approach. Maritime Economics & Logistics 7(4): pp. 315.

Barros, C.P. and Athanassiou, M. (2004) Efficiency in European seaports with DEA: Evidence from Greece and Portugal. Maritime Economics & Logistics 6(2): pp. 122-140.

Bruzzone A.G., Mosca R., Rapallo S. (1999). Risk Analysis In Harbours Environment By Using Simulation. Proceedings of TIEM99, Delft, NL, June 8-11.

Charnes A, Cooper WW and Rhodes E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6): pp. 429-444.

Coto Millan, P.; Banos Pino, J. and Rodrigues Alvarez, A. (2000). Economic Efficiency in Spanish Ports: Some Empirical Evidence. Maritime Policy & Management 27(2): pp. 169-175.

Cullinane, K. P. B. Song, D.W. and Gray, R. (2002). A Stochastic Frontier Model of the Efficiency of Major Container Terminals in Asia: assessing the influence of administrative and ownership structures. Transportation Research Part A, (36): pp. 734-762.

Cullinane, K. P. B. and Song, D.W. (2003). A Stochastic Frontier Model of the Productive Efficiency of Korean Container Terminals. Applied Economics 35(3): pp. 251-267.

Cullinane Kevin, Ping Ji, Teng-fei Wang. (2005). The relationship between privatization and DEA estimates of efficiency in the container port industry. Journal of Economics and Business 57: pp. 433-462.

Cullinane Kevin, Ping Ji, Teng-fei Wang. (2004). An Application of DEA Windows Analysis to container port production. Journal of Review of network Economics 3(2): pp. 184-206.

Cullinane Kevin, Dong-Wook Song, Tengfei Wang. (2005). The Application of Mathematical Programming Approaches to Estimating Container Port Production Efficiency. Journal of Productivity Analysis 24: pp. 73-92.

Cullinane Kevin, Ping Ji, Teng-fei Wang. (2006). the efficiency of European container ports: a cross-sectional data envelopment analysis. International Journal of Logistics: Research and Applications 9(1): pp. 19-31.

Cullinane, K.; Wang, T.F.; Song, D.W. and Ji, P. (2006). The technical efficiency of Container Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis. Transportation Research Part A 40: pp. 354-374.

Dirk Steenken, Stefan Voβ, and Robert Stahlbock. (2004). Container terminal operation and operations research- a classification and literature review. OR Spectrum 26(1): pp.

Estache, A.; Gonzalez, M. and Trujillo, L. (2001). Efficiency Gains from Port Reforms and the Potential for yardstick Competition: Lessons from Mexico. World Development 30(4): pp. 545-560.

García C. R. and H. Marín (internet). An Integration Model to Study The Structural and Financial sustainability of Agricultural Enterprises.

Greasley A. (2004). Using DEA and simulation in guiding operating units to improve performance. Journal of the operational Research Society 56: pp. 727-731

Haralmbides, HE, Verbeke, A, Musso, E. and Benacchio, M. 2001. Port Financing and pricing iin the European Union: Theory, politics and reality. International Journal of Maritime Economics 3; 368-386.

Hartmann, S. (2004). Gererating scenarios for simulation and optimization of container terminal logistics. OR Spectrum 26(2): pp. 171-192.

Hidekazu ltoh. (2002). Efficiency Changes at Major Container Ports in Japan:

Jim Dai, Wuqin Lin, Rajeeva Moorthy, Chung-Piaw Teo. (2006). OR Spectrum, Special Issue in Container Logistics. 28(s): pp. 495-518.

Jill Johnes (2003). Measuring Teaching Efficiency in Higher Education: An Application of DEA to Graduates from UK Universities 1993. Internet.

Lee Chee Xui (2005). Thesis on Malaysian Container Port Performance Measurement. Malaysia University of Science and Technology.

Liu, Z. (1995). The Comparative Performance of Public and Private Enterprises. Journal of Transport Economics and Policy, 29, 3: 263-274.

Löthgren Mickael (1997). Bootstrapping DEA-Based Efficiency Measures and Malmquist Productivity Indices: A Study of Swedish Eye-Care Service Provision. Routledge, pert of the Taylor & Francis Group 6(11): pp. 707-710.

Löthgren Mickael (1992). How to Bootstrap DEA Estimators: A Monte Carlo Comparison.

Manuel Muñiz, Joseph Paradi, John Ruggiero, Zijiang Yang (2006). Evaluating alternative DEA models used to control for non-discretionary inputs. Computers and Operations Research 33(5): pp. 1173-1183.

Martinez Budria, E.; Diaz Armas, R. and Navarro Ibafiez, M. and Ravelo Mesa, T. (1999). A Study of the Efficiency of Spanish Port Authorities Using Data Envelopment Analysis. International Journal of Transport Economics 2: pp. 237-253

McMullen Patrick R., Gregory V. Frazier (1998, 2004). Using Simulation and Data Envelopment Analysis to Compare Assembly Line Balancing Solutions. Journal of Productivity Analysis 11: pp. 149-168.

McMullen Patrick R.(2000). Selection of Notebook Personal Computers Using DEA. The southern Business and Economic Journal 23(3): pp. 200-214.

Merkuryev G., Merkuryev Y., Tolujev J. (2000). Computer Simulation and Metamodelling of Logistics Processes at a Container Terminal. Studies in Informatics and Control. 9(1): pp. 53-59.

Mat T. Razman, K. Hussain. (2000). Simulation and Analysis for the Kelang Container Terminal Operations. Logistics Information Management 13(1): pp. 14-20.

Marlow Peter B., Ana C. Paixão Casaca. (2004). Measuring Lean Ports Performance. International Journal of Transport Management 1(4): pp. 189-202.

Löthgren Mickael (1999). Bootstrapping the Malmquist productivity index – a simulation study. Routledge, pert of the Taylor & Francis Group 6(11): pp. 707-710.

Nevins M.R., Macal C.M., Joines J. (1998). A Discrete-Event Simulation Model for Seaport Operations. SUMLATION, 70(4): pp. 213-223.

Notteboom T., Coeck C. and Van Den Broeck J. (2000). Measuring and Explaining the Relative Efficiency of Container Terminals by Bayesian stochastic frontier models. Int. J. Mar. Econ. 2: pp. 83-106.

Park, Ro Kyung and De, Prabir 2004: An Alternative Approach to Efficiency Measurement of Seaports. Maritime Economics & Logistics 6: pp. 53-69.

Park Ro-Kyung and Prabir De. (2004). an Alternative Approach to Efficiency Measurement of Seaports. Maritime Economics & Logistics 6:pp. 53-69.

Poitras G., Jose Tongzon and Hongyu Li. (1996). Measuring Port Efficiency: An application of Data Envelopment Analysis. http://www.bus.sfu.ca/homes/poitras/PORTS2.pdf

Rios, L.R. and Maçada, A.C. G. 2006. Analysing the relative efficiency of container terminals of Mercosur using DEA. Maritime Economics & Logistics, 8, 4, 331-346.

Roll Y. and Hayuth, Y. (1993). Port Performance Comparison Applying Data Envelopment Analysis (DEA). Maritime Policy and Management 20(2). Pp. 153-161.

Settlage, Daniel M. (2003). Robustness of non-parametric measurement of efficiency and risk aversion: A simulation analysis with applications to agricultural banking and Ethiopian farming. Thesis of PhD PURDUE University Publication No.AAT3124220. Pp.1-147.

Scott M. Shafer and John W. Bradford (1995). Efficiency Measurement of Alternative Machine Component Grouping Solutions Via Data Envelopment Analysis. IEEE Transaction on Engineering Management 42(2): pp. 159-165.

Song, D.W. and Cullinane, K. (2001). The administrative and ownership structure of Asian Container Ports. International Journal of Maritime Economics 3(2): pp.

175-197.
Tongzon Jose (2001). Efficiency Measurement of selected Australian and other international ports using data DEA. Transportation Research Part A, Policy and Practice 35(2): pp. 113-128.

Tongzon, J, 2005. Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). Transportation Research Part A – Policy and Practice 39: pp. 405-424.
Toshiyuki Sueyoshi (1992). Measuring Technical, Allocative and Overall Efficiencies Using a DEA Algorithm. Journal of Operational Research Society 43(2): pp. 141-155.
Trujillo, L. and Tovar, B. (2007) The European Port Industry: An Analysis of its efficiency. Maritime Economics and logistics, 9,2, 148-171.
Valentine V.F. and Gray R. (2001). The measurement of port efficiency using data envelopment analysis. Proceeding of the Ninth World Conference on Transport Research, Seoul, 22-27 July.
Valentine V.F. and Gray R. (2002). An Organizational Approach to Port Efficiency. Proceeding IAME Panama Conference, International Steering Committee, 13-15 November 2002 Panama.
Yun Zhang and Robert Bartels. (1998). The Effect of Sample Size on the Mean Efficiency in DEA with an Application to Electricity Distribution in Australia, Sweden and New Zealand. Journal of Productivity Analysis 9(3): pp. 187-204.
Wang Teng-Fei, Dong-Wook Song, Kevin Cullinane. (2003). Container Port Production Efficiency: A Comparative Study of DEA and FDH Approaches. Journal of the Eastern Asia Society for Transport Studies 5: pp. 698-713.
Wang Teng-Fei, Kevin Cullinane. (2006). The Efficiency of European Container Terminals and Implications for Supply Chain Management. Maritime Economics & Logistics 8: pp. 82-99.
William W. Cooper, Lawrence M.Seiford, Kaoru Tone (2000). Data Envelopment Analysis: A Comprehensive Text with Models, Application, Reference and DEA-Solver Software©2002 Kluwer Academic Publishers, New York, Boston, Dordrecht, London, Moscow.

Table 2: Summary of Papers in ports efficiency

Papers	Method	Units	Inputs	Output
Roll and Hayuth (1993)	To theoretically rate the efficiency of ports DEA–CCR Model	Hypothetical Numerical use 20 ports	Manpower,Capital, Cargo uniformity	Cargo throughput, level service, consumer satisfaction, ship calls
Liu (1995)	Translog production function	28 British port authorities for 1983 to 1990	Movement of freight (ton)	Turnover
Martinez Budria, Diazmodel Armas, Navarro Ibanez and Ravello Mesa (1999)	DEA-BCC Model To examine the relative efficiency of ports and efficiency an individual of each port	26 Spanish ports, 1993 to 1997	Labour expenditure, depreciation charge, other expenditure	Total cargo moved through docks, revenue obtained from rent of port facilities
Coto Millán, Baños Pino and Rodriguez Alvarez (2000)	Translog Cost model	27 Spanish Ports for 1985 to 1989	Cargo handled (ton)	Aggregate port output(includes total goods moved in the port in thousand tones, the passenger embarked and disembarked of vehicles with passengers)
Tongzon (2001)	DEA-CCR additive Model. Specify and empirically test the various factors which influence the performance and efficiency of a port	4 Australian and 12 other international ports for 1996	Number of cranes, number of container berth, number of tugs, terminal area, delay time, labour	Cargo throughput, ship work rate
Estache, Gonzalez and Trujillo (2001)	Translog and Cobb-Douglas production frontier model	14 Mexican ports for 1996 to 1999	Containers handled (tons)	Volume of merchandise handled

Papers	Method	Units	Inputs	Output
Valentine and Gray (2001)	DEA-CCR Comparing port efficiency to find if ownership and organizational structure leads to more efficiency	31 CT out of the world's top 100 CT for the year 1998	Total length of berth, container berth length	Number of containers, total tons throughout
Barros (2003a)	DEA-allocate and Technical Efficiency	5 Portuguese seaports, 1999-2000	Number of employees, book value of assets	Ships, movement of freight, gross tonnage, market share, break-bulk, liquid bulk, containers, Ro-Ro, salaries labor, capital
Barros (2003b)	DEA-Malmquist index and a Tobit model	10 Portuguese seaports for1999-2000	Number of employees and book value of assets	Ship, movement of freight, break-solid bulk cargo, containers, solid, liquid bulk
Cullinane and Song (2003)	Stochastic Cobb-Douglas production frontier :half normal, exponential, truncated models	5 CT , Korean and UK, different year of (65 observations)	Fixed capital in euros (1998=100)	Turnover derived from the provision of CT services, but excluding property sales
Park and De(2004)	DEA-CCR and BCC	11 Korean seaports for 1999	Berthing capacity, ships calls, Cargo handling(ton)	Cargo throughput, ships calls, revenue and consumer satisfaction
Borros and Athanassiou (2004)	DEA-CCR and BCC	2 Greek and 4 Portuguese seaports	Labour and capital	Ships calls, movement of freight, cargo handled, container handled
Barros (2005)	Stochastic Translog Cost frontier	10 Portuguese seaports for 1999-2000	Price of labour, price of capital, ships, cargo	Total cost
Cullinane, Song and Wang (2005)	DEA-CCR and BCC And FHD models	57 international CT seaports in 1999	Container throughput	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries

Papers	Method	Units	Inputs	Output
Tongzon and Heng (2005)	Stochastic Cobb-Douglas model and a competitiveness regression.	25 international CT	Container throughput	Terminal quay length, number of quay cranes, port size measure by a dummy which is exceed one million TEU and private participation in the port
Cullinane, Song, Wang and Ji (2006)	Stochastic Cobb-Douglas and DEA models	28 international CT for 1983-1990	Container throughput	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries