AN EFFICIENCY ANALYSIS OF SEAPORTS USING EXTENDED WINDOW ANALYSIS, MALMQUIST INDEX AND SIMAR-WILSON APPROACH

by

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LIST OF ABBREVIATION

AE	=	Allocative Efficiency
AGV	=	Automated Guided Vehicle System
BCC	=	Banker, Charnes and Cooper
BCC-O	=	Banker, Charnes and Cooper Output Oriented
CCR	=	Charnes, Cooper and Rhodes
CCR-I	=	Charnes, Cooper and Rhodes Input Oriented
COLS	=	Corrected Ordinary Least Squares
CPU	=	Central processing Unit
CRS	=	Constant Returns to Scale
CT	=	Container Terminal
Cte/-	=	Constant Return to Scale
DEA	=	Data Envelopment Analysis
DEAP	=	Data Envelopment Analysis Program
DMU	=	Decision Making Unit
DMU_k	=	The k^{th} DMU
DPS	=	Data Processing System
Drs/DRS	=	Decreasing Return-to-scale
DWT	=	Dead Weight Tonnage
EDI	=	Electronic Data Interchange
EDP	=	Electronic Data Processing
FDH	=	Free Disposal Hull
FP	=	Fractional Programming
GAMS	=	General Algebraic Modeling System

GDP	=	Gross Demotic Product
HDI	=	Human Development Index
i	=	The subscript of inputs (i=1,2,..,m)
IRS/Irs	=	Increasing return to scale
j	=	The subscript of DMUs (j=1,2,…,m)
k	=	The specific element related to DMU measured $1 \leq k \leq n$
LP	=	Linear Programming
m	=	The number of input variables for a DMU
MPSS	=	The most productive scale size
r	=	The subscript of outputs (r=1,2,…,s)
s	=	The number of output variables for a DMU
N	=	Number of DMUs
OLS	=	Ordinary Least Squares
P	=	The production possibility set
PTE	=	Pure technical efficiency
RTGs	=	Rubber Tyred Gantry are used at container terminals
RTS	=	Return to scale
s-	=	Slack an input excesses
s+	=	Slack an output shortfall
S.D	=	Standard Deviation
S.t.	=	Subject to
S.E	=	Scale Efficiency
SFA	=	Stochastic Frontier Analysis
t	=	The t^{th} time period
T	=	Number of time periods

TE	=	Technical Efficiency
TEUs	=	Twenty-foot Equivalent Units
TFP	=	Total Factor Productivity
u_r	=	The weighting variable for the rth output
UNCTAD	=	United Nations Conference on Trade and Development
v_i		The weighting variable for the ith input
VRS	=	Variable Returns to Scale
x	=	An activity vector of input
X	=	The matrix of input variables
x_{ij}	=	The i^{th} input data for the DMU_j
y	=	An activity vector of output
y_{rj}		The r^{th} output data for the DMU_j
Y	=	The matrix of output variables
λ	=	Weight
λ_j	=	The j^{th} weight
ϕ_k	=	The DEA efficiency score of DMU_k

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SATU ANALISIS KECEKAPAN BANDAR PELABUHAN MENGGUNAKAN ANALISIS TETINGKAP TERPERLUAS, INDEKS MALMQUIST DAN PENDEKATAN SIMAR-WILSON

ABSTRAK

Sumbangan bandar pelabuhan kepada ekonomi negara di dunia tidak dapat dinafikan. Pelbagai kaedah pengawasan digunakan untuk mengukur daya saing bandar-bandar pelabuhan tersebut dengan keputusan yang berbeza. Maka, adalah penting untuk menganalisis kecekapan aktiviti bandar-bandar pelabuhan serta mencari peralatan yang lebih baik untuk meningkatkan lagi pengeluaran bandar-bandar pelabuhan ini. Objektif penyelidikan ini adalah untuk menilai kecekapan bandar-bandar pelabuhan terlibat untuk perancangan masa hadapan dan strategi pengoperasian, peningkatan pengeluaran melalui hub punggahan sementara dan memperkenalkan metodologi terperluas untuk bandar-bandar pelabuhan.

Metodologi yang digunakan dalam kajian ini memberikan maklumat berkenaan asas-asas teori bagi model-model DEA (Data Envelopment Analysis) dan FDH (Free Disposal Hull) yang boleh diaplikasikan. Dalam penyelidikan ini, analisis data keratan rentas dan data panel untuk tahun 2000-2005 dari 22 buah bandar pelabuhan dan terminal kontena di Timur Tengah dan Afrika Timur dianalisis untuk menganggar skor kecekapan dan prestasi. Skor kecekapan dan prestasi dinilai menggunakan model-model DEA-CCR (Charnes, Cooper and Rhodes), DEA-BCC (Banker, Charnes and Cooper), superkecekapan; analisis tetingkap CCR, BCC, indeks Malmquist dan model FDH (Free Disposal Hull). Sumbangan penyelidikan ini bertumpu kepada metodologi terperluas menggunakan model-model superkecekapan di dalam analisis tetingkap, indeks Malmquist dan pendekatan Simar

dan Wilson untuk bandar pelabuhan. Selain itu, jarak disertakan sebagai parameter untuk menilai kecekapan bandar pelabuhan. Satu model hub serantau dicadangkan untuk meningkatkan lagi proses punggahan sementara di rantau tersebut. Perbandingan di antara DEA dan FDH dijalankan untuk mengenalpasti metodologi yang berpotensi.

Hasil keputusan menunjukkan keadaan turun naik dalam skor kecekapan bandar pelabuhan yang disebabkan oleh ciri-ciri ekonomi dan politik yang pelbagai di negara-negara serantau Timur Tengah dan Afrika Timur. Lokasi strategik rantau tersebut serta pembangunan ekonominya yang pesat dalam pelbagai domain akan menuntut peningkatan dalam sektor maritim.

AN EFFICIENCY ANALYSIS OF SEAPORTS USING EXTENDED WINDOW ANALYSIS, MALMQUIST INDEX AND SIMAR-WILSON APPROACH

ABSTRACT

The contribution of seaports to the economies of world countries is undeniable. Different monitoring mechanisms are used to measure the competitiveness with differing results. As such, it is important to analyze the efficiency of port activities; looking for better tools to improve production/service of these seaports. The objectives of this research are to highlight the seaports under consideration, evaluating their efficiencies for the purpose of future planning and operating strategies, increasing the seaports production through the transshipment hubs and introducing an extended methodology for seaports.

The methodology used provides information concerning the theoretical foundations of the DEA (Data Envelopment Analysis) and FDH (Free Disposal Hull) models that could be applied. In this research an analysis of cross-section and panel data, for the years 2000-2005 from the 22 seaports and containers terminals under study in the Middle East and East Africa are analyzed for estimating the efficiency score and performance. The efficiency score and performance are evaluated by applying DEA-CCR (Charnes, Cooper and Rhodes), DEA-BCC (Banker, Charnes and Cooper), superefficiency; window analysis CCR, BCC, Malmquist index and FDH (Free Disposal Hull) models. The contributions of this research are focused on extended methodology using superefficiency in window analysis, Malmquist index and Simar and Wilson approach models in seaports. Apart from that, distance is included as a parameter to evaluate seaport efficiency; finally a regional hub model is

proposed to improve the transshipment in the region. DEA versus FDH comparison is carried out to identify the potential methodology.

The results show fluctuation in the efficiency score of seaports, due to the various characteristics of the economic and politic situation of the countries in the Middle East and East Africa. The strategic location of the region and significant economic development in various domains will require an improvement in the maritime sector.

CHAPTER 1
INTRODUCTION

1.1 Background

Seaports, serving as the interface between maritime and inland transportation, play a significant role in the economic development of a region (*Figure 1.1.*).

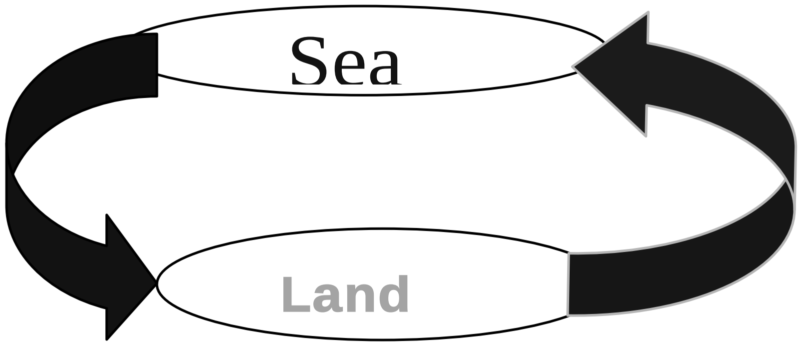

Figure 1.1: General Movement of Merchandise between Maritime and Inland

Maritime transport was, and currently is, the backbone of development for many countries (Cullinane et al., 2002); and therefore, production capabilities and the performance measurement of seaports have always been major issues in seaport management. Besides functioning as a powerful management tool for seaport operators, seaport performance measurement also functions as an important input for regional and national seaport planning and operations.

One of the most important aspects to measure seaport performance is the efficiency, and to evaluate efficiency, the popular method of Data Envelopment Analysis (DEA) is commonly used (Forsund & Sarafoylou, 2002).

In the past, many studies dealing with efficiency of seaports using DEA have been conducted; however, most of these studies compare the efficiency of seaports in the European countries (Trujillo & Tovar, 2007); (Barros, 2006); (Barros & Manolis, 2004); (Cullinane et al., 2006), with a few dealings with some Asian countries and Australia (Cullinane et al., 2005); (Lee, 2005); (Tongzon, 2005). Nevertheless, none of the studies conducted so far has focused on seaports in the Middle Eastern and East African countries where maritime transport in the past and at present is the economic backbone of these countries. Specifically, in the past few decades seaport industry has witnessed a remarkable development in the countries of East Africa, such as Sudan, Eritrea, Djibouti, Kenya, and Tanzania, as well as those in the Middle Eastern region, such as Saudi Arabia, Yemen, Oman, the United Arab Emirates, and Iran. These countries possess seaports which are critical in terms of their geographic locations of the international maritime trade route between the East and the West.

These seaports are considered as middle distance seaports at which goods carried from Europe and Far East/Australia and vice versa can be exchanged and transshipped to all countries in the Middle East, along the Red Sea and East Africa (*Figure 1.2.*). Since older days, these seaports have been providing services for the regional coasters, and with the passage of time, have developed to rank among the important maritime international trade centre in the Middle East and East Africa. The strategic/geographic location of some of these seaports have 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).

The privilege of sea transportation is the speed, comfort, safety, and the possibility as well as the ability to handle heavy traffic of goods and passengers at low cost. Through the years, the operations at seaports have become more and more complex as the new technology imposes new requirements in the infrastructure and handling of materials.

This thesis aims to apply the economic theories underpinning the maritime cargo industry, which indicate the total production over the total of resources is equal to 1. On the basis of this economics, producers are travelling from seaport to seaport searching for cheaper shipping costs as well as access to the end markets. The competition of seaport industry emerges through the factors, such as services provided in inland operations in terms of loading/unloading, storage capacity, and transshipment, while lower costs and shorter waiting time for ships at seaports are the most attractive factors for shipowners. In addition, in order for the seaport industry to be highly productive, good infrastructure and modern sophisticated handling equipment to manipulate cargoes and containers in a short time from/to the ships are needed.

Based on these basic elements, this thesis provides empirical analysis and translates these economic theories into seaport industry and suggests improved approaches for evaluating and measuring the seaport efficiency. The analysis was used several models to analyse the data and determine its validity for seaports efficiency. Data envelopment analysis (DEA) and Free Disposal Hull (FDH) are two most important non-parametric methodologies to measure the efficiency. Superefficiency in DEA allows ranking the units in correct order. DEA with panel data provides window analysis model, with the capability to test the performance and stability of unit over time. Malmquist index use the technical efficiency change (TEC) and technical change (TC). These two forms involve the component of distance function.

Although the efficiency scores obtained from solving linear programming problems for DEA models represent the ability of management to convert inputs into outputs at the current scale of operation, it is possible that some other external factors, beyond the control of management, may affect efficiency such as Gross Demotic Product (GDP) and Human Development Index (HDI). To incorporate that external factors the analysis of simar and Wilson approach is used.

1.2 Research Problems

Most of the studies dealing with seaports efficiencies evaluate the efficiency of only European seaports, some Asian seaports and Australia seaports. Nevertheless, none of these studies focuses on Middle East and East Africa so far. Apart from that, a general view on the strategic/geographic location of some regional seaports shows that there are no transshipments Hubs linking the Middle East and East Africa seaports.

Some seaports in the Middle East and East Africa have also long since known but unfortunately, they are paralysed as compared to the seaports in the West and East regions (Europe, Asia). Besides, a survey visit to some seaports with adequate infrastructure and facilities shows that they are having low productivity due to the lack of management skill while some countries in the Middle East and East Africa have lots of ineffective seaports, (United Nations Conference on Trade and Development) (UNCTAD, 2004a, 2004b, 2004c; 2006).

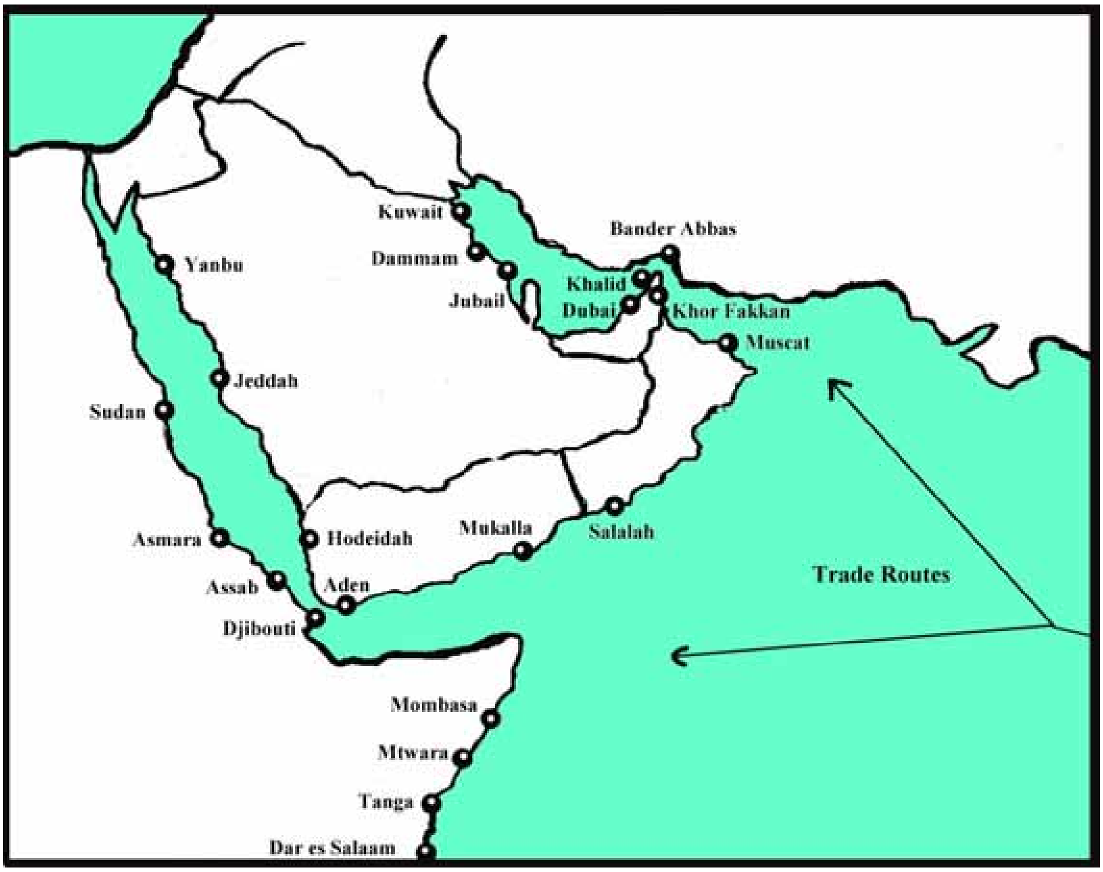

Figure 1.2: Map Showing Strategically Important Seaports in the Middle East and the East African Regions

Lastly, the exclusion of seaport distance has occurred in terms of the evaluation of the seaport efficiency (Barros & Manolis, 2004); (Cullinane et al., 2006). Hence, based on the above-mentioned situations, the research relating to this research work are as follows:

1. To study and evaluate the efficiency of the Middle East and East Africa seaports.
2. To study the objective of having the transshipment Hubs link in the Middle East and East Africa.
3. To trigger the paralytic seaports.
4. To increase productivity and efficiency of some seaports.
5. To rectify the negligence in the evaluation of the seaport efficiency.

1.3 Research Motivations

The Middle East and East Africa is currently witnessing significant economic development in various domains and some of these seaports have distinction owing to their distinguishing infrastructure and equipment for transshipment purposes.

Apart from that, the Middle East and East Africa has similar marine topographies which are suitable for navigation purposes as well as to enjoy suitable weather conditions (temperature and wind) almost throughout the year (A.M.T.A., 1975). The motivation is also to highlight the seaports industry in Middle East and East Africa (*Figure 1.3*) as well as to determine the performance and the stability of these seaports. Lastly it is to activate the maritime traffic in the Middle East and East Africa.

1.4 Research Objectives

The objectives of this thesis are as follows:

1. To highlight the importance of the geographic location of the seaports under consideration.
2. To apply economic theories underpinning the seaports industry in evaluating the relative efficiency, and to interpret the obtained results in improving the efficieny of seaports.
3. To propose the most suitable location for transshipment hubs.
4. To incorporate the distance as an influential parameter in the seaport efficiency analysis.
5. To enhance the existing DEA methods and use them in the efficiency analysis of seaports.

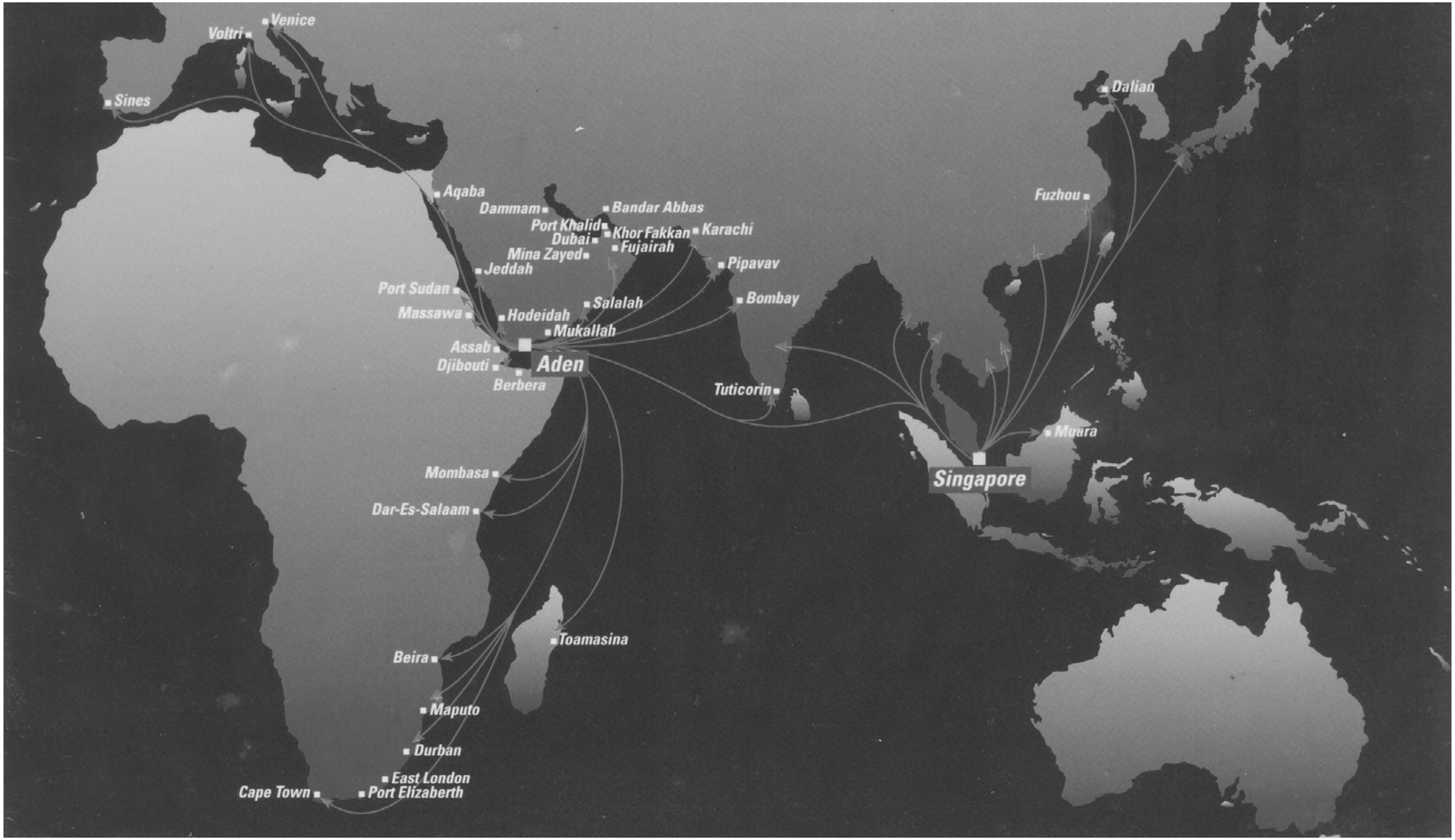

Figure 1.3: The International Main Marine Routes. Source (Yeminvest, 1999)

1.5 Research Approach

Data envelopment analysis (DEA) and Free Disposal Hull (FDH) are two most important non-parametric methodologies to measure the efficiency. DEA CCR (Charnes, Cooper and Rhodes), DEA BCC (Banker, Charnes and Cooper) and FDH output-oriented models are used to analyse 22 seaports in the Middle East and East Africa. In order to estimate the production frontier, data were colleted for the years 2000-2005.

The initial cross-section data used follow by an analysis of DEA CCR, BCC and FDH and a comparison of both to identify the potential methodology, finally to get more information panel data used for in depth analysis using window analysis, Malmquist index and simar and Wilson approach. The distance was use as new parameter in seaports efficiency analysis. Finally from the results of analysis the most suitable transshipment hubs are proposed.

1.6 Thesis Outline

The rest of the thesis is organized in five chapters described below: Chapter Two presents a review of the literature related to the study and contains an introduction, seaport operations, DEA with cross-section data as well as Panel data at the study seaports. Chapter Three presents a review of the methodology of using DEA models as well as a two-stage procedure for analysis. Chapter Four presents data analysed by using cross-section data (Classical Techniques) and superefficiency method to determine the cargoes and containers efficiency. Chapter Five presents' data analysis using panel data models applied such as window analysis, Malmquist models; and Simar and Wilson approach. Chapter Six includes conclusions based on results presented in Chapter Four and Five; suggestions for future work are also made in this chapter.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter, reviews of literature followed by pertinent references related to the seaport studies in terms of performance efficiency are presented. This review allows the readers to understand this specific area of research and the tools employed to conduct this research.

2.2 A Brief Review of the Seaports in the Region under Study

Maritime transportation growth today is rapidly increasing as can be evidenced by the recent development and improvement of many seaports in the world. Example, an average in millions tonnage of dead weight tonnages (dwt) was increased by 3.7% in Asian countries, while this incensement was 0.3% in the African countries for the period of 1970-1991 (UNCTAD, 2004c). In 1991, Kuwait and Saudi Arabia (in our study zone) were among the 35 most important maritime countries according to the data supplied by the shipping information services of Lloyd's (Behnams, 1994).

Ravindra (2003) selected four seaports from region under study (Dubai, Khor Fakkan, Salalah and Aden) and four more neighbourhood seaports and link seaports and compared their efficiency and productivity. He found that the four seaports selected for the purpose of this study was highly competitive and productivity.

Table 2.1: Average Productivity of Selected Seaports Measured by Moves per Hour of Crane and Berth for Small and Large Vessels.

Seaport	Crane productivity for small vessel	Berth productivity for small vessels	Crane productivity for large vessel	Berth productivity for large vessels
Dubai*	22	40	30	110
Khor-Fakkan*	20	32	28	100
Salalah*	N/A	N/A	29	90
Aden*	N/A	N/A	28	70
Singapore PSA	23	45	36	140
Nhava Sheva**	18	30	22	40
Jawahrlal Nehru**	16	24	20	36
Colombo-SLPA**	14	23	18	45

Small vessels: 400-800 TEU.
Large vessels: 1800 TEU and upwards.
*: Seaports under study.
**** Neighboring seaports.**
N/A: data not available.

Source (Ravindra, 2003)

As can be seen in *Table 2.1*, the productivity of Arabian seaports in terms of moves per hour is greater by a factor ranging from 2-65 compared to some neighbouring seaports**, such as Indian seaports and Colombo (excluding Singapore). A review of maritime exhibits for 50 seaports of developing countries revealed that Dubai, Saudi Arabia, Oman, Iran, Sudan, Tanzania, Djibouti, and Yemen had a growth rate of: 0.05, 11.6, 14.6, 48.8, 28.2, 1.5, -6.4, and 52.1 in 2000-2001, while in 2001-2002 this rate has amounted to 15.5, 15.1, 6.3, 30.8, 4.6, 10.0, 20.6, and 2.9, *Table 2.2*.

Table 2.2: The Growth Rate of Seaport Production for 2000-2002.

Year	Dubai	Saudi Arabia	Oman	Iran	Sudan	Tanzania	Djibouti	Yemen
2000-2001	0.05	11.6	14.6	48.8	28.2	1.5	-6.4	52.1
2001-2002	15.5	15.1	6.3	30.8	4.6	10	20.6	2.9

Source (UNCTAD, 2004a)

In 2003, the throughput at Salalah seaport increased by 56% where gross crane productivity averaged 30.4 moves per hour with peaks of 33 moves per hour. At this seaport, the addition of handling equipment (rubber–typed yard gantry cranes) resulted in the performance increase of the seaport by 70% during 2002 and 2003 (UNCTAD, 2004a; 2004b; 2004c; 2006).

The export and import at the seaport of Mombassa, Kenya, increased in the year 2000 from 1.7 to 2.5 Dwt (millions), while in 2004 from 7.2 to 10 Dwt (millions). However, in March 2004, a delay surcharge of US $70.00 per TEU vessel in Mombasa was imposed due to the poor seaport production in terms of overall net income (UNCTAD, 2004a; 2004b; 2004c; 2006).

During 2003, overall performance of seaports in the study region was hampered by 4% to 6% for several reasons but most likely due to the Gulf War and related increases in insurance premiums or lack of insurance for same specific seaports of the region; in consequence, many international maritime companies avoided transshipment from these seaports (UNCTAD, 2004c).

In the past 5 years, a number of incentives and investment opportunities have been announced by UNCTAD in order to develop and extend the infrastructure and handling equipment for the ultimate improvement of efficiency and performance at the Asian and European seaports (UNCTAD, 2004a, 2004b, 2004c; 2006).

2.3 Efficiency Analysis on Seaports

There are more models used cross-section and panel data, such as the Data Envelopment Analysis Program (DEAP) software and the frontier version 4 for econometric frontiers developed in DEA SFA by Coelli, (1996); Coelli et al., (1998), and Thanassoulis (2001). The cross-section data is a quantity that represents or traces the values taken by a variable relating to one period such as a month, quarter, or year (BusinessDictionary.com, 2009a). In contrast, panel data is quantities that represent or trace the values taken by variables over periods such as months, quarters, or years, (BusinessDictionary.com, 2009b).

Roll & Hayuth (1993) presented a theoretical exposition and suggested to use cross-section data to operationalise their approach. In addition, they modeled explicitly the multi-product of seaports efficiency and service level such as handling rate time. The seaport performance indicators suggested by UNCTAD (1976) are shown in *Table 2.3*.

2.3.1 Cross-section Data Models

2.3.1.1 Studies applied in Western Seaports

There is extensive literature on DEA, applied to a wide diversity of economic fields and in particular to seaport transportation. Cullinane et al. (2005) used DEA to highlight seaport privatization, the objective of their study was to improve the efficiency of this sector, using container throughput as output, while terminal area, berth length, quay crane, yard crane, and straddle, as inputs. They concluded that public and private/public seaports perform better than public/private and private seaports. Bendall & Stent (1987), Tabernacle (1995) and Ashar (1997) considered that cargo handling berth productivity as the efficiency estimate of seaports. Roll & Hayuth (1993) presented a theoretical exposition and proposed use the cross-sectional data for financial reports in order to render the DEA approach operational. These authors observed that the seaports which were already redeveloped could receive large-sized container vessels and increase their productivity.

Valentine & Gray (2002) focused on the seaports of North America and Europe for comparing efficiency where they assumed that there are many factors for evaluating the seaport performance, such as location, infrastructure, and connectivity to other seaports. They used data for 1998 which constituted number of outputs, such as containers as total throughput, and inputs, such as total length of berth, and container berth length. These authors concluded that DEA is useful to test the container seaport efficiency and highlighted the characteristics of an efficient seaport.

Wang et al. (2003) analyzed the container terminal seaport efficiency using two alternative techniques: DEA-CCR, DEA-BCC; and Free Disposal Hull (FDH) models. They applied these models on a sample size of the 2001 top 30 container ports in the world, using throughput as output, and quay length, area, quay crane, yard crane and straddle carrier as inputs. The comparative analysis revealed that the two methods (DEA and FDH) tend to give significantly different results. Similarly, Cullinane et al. (2005) measured the efficiency of the most 57 important terminal ports in the world using two alternative techniques, DEA-CCR, DEA-BCC and the FDH models, using 2001 cross-section data. These authors also concluded that the analysis of efficiency estimated by DEA-CCR, DEA-BCC and FDH models tend to give significantly different results.

Cullinane et al. (2006) applied both approaches, DEA and Stochastic Frontier Analysis (SFA), to estimate the efficiency of the world's container terminals for the year 2001 and compared the obtained results. They concluded that overall score of stochastic frontier analysis (SFA) was better than that of DEA but the cross-section data of one year may not be wholly appropriate to capture multi-period optimization, but is useful for a particular year. Tongzon (1995) using the DEA method measured the efficiency of 16 selected international ports and showed that 10 studied container ports were efficient while 6 were inefficient.

Lin & Tseng (2005) applied DEA-CCR, DEA-BCC, and SFA (Cobb-Douglas and Translog function) models to measure the efficiency of 27 international container ports, using cross-section data for the years of 1999-2002. They concluded that the total average score for the SFA models was larger than DEA models in measuring port efficiency.

Martinez-Budria et al. (1999) applied DEA on 26 Spanish ports that were divided into three groups namely, 'high complexity ports', 'medium complexity ports', and 'low complexity ports'. After examining the efficiency of these ports using DEA-CCR and DEA-BCC models, these authors concluded that high complexity ports were associated with high efficiency, compared with the random mix of medium and low efficiency found in the other two types of ports.

Barros (2003a) analysed technical and allocative efficiency of Portuguese ports for the port regulatory procedures intended to provide incentives for increasing productive efficiency. He concluded that the incentive regulation carried out by the government regulatory body, the Maritime Port Agency, is not achieving its aims, and proposes a policy revision to enforce efficiency, based on a governance environment.

Notteboom et al. (2000) applied a Bayesian approach based on Monte-Carlo approximation to the estimation of a SFA model aimed at assessing the productive efficiency of 36 European container terminals located in the Hamburg-Le Havre range and in the Western Mediterranean. The analysed data relates to the single year of 1994. The robustness and validity of the estimated model was tested by comparing the results with those of four benchmark terminals in Asia (Singapore, Kaohsiung and Hong Kong's MTL and HIT terminals). He concluded that north European container terminals were more efficient.

Valentine & Gray (2001) applied the DEA-CCR model for 31 container seaports among the world's top 100 container seaports in 1998 to examine the relationship between certain types of port properties, such as waiting time, time around, and organizational structures, with efficiency, and concluded that such relationships lead to higher efficiency. Wang & Cullinane (2006) focused on measuring the efficiency of container terminals in Europe using 2003 data. They used DEA CCR and BCC models; they found that the terminals are inefficient. Their paper serves to supplement the existing studies by deriving estimates of relative efficiency for a sample comprising 69 European container terminals with throughput of over 10,000 TEUs. Wang & Cullinane (2006) also discussed the scale properties of the container terminal production.

2.3.1.2 Studies applied on Eastern Seaports

Cullinane & Song (2003) estimated productivity function for increasing the production of Korean container terminals by evaluating the privatization policies, where they applied the stochastic frontier model as a justified methodology and used the cross-sectional data. Park & De (2004) focused on the measurement of productivity, profitability, and marketability of 11 Korean seaseaports using the congestion and factor efficiency with CCR and BCC models for 2001 data. They measured the efficiency of productivity, profitability, and marketability in three stages, while the fourth stage measured the overall efficiency, using berth capacity, and cargo handling capacity as inputs, while cargo throughput, number of ships, and revenue and customer satisfaction as the outputs. They concluded that DEA is a practical approach to evaluate the overall efficiency of seaports.

Using both DEA-CCR and DEA-additive models, Tongzon (2001) studied the efficiency of 4 Australian and 12 other international container seaports for the year 1996 including Yokohama and Osaka seaports and identified that the seaports of Melbourne, Rotterdam, Yokohama, Osaka and all others in the analysis were the most inefficient mainly due to the extent of slack in the inputs.

Cullinane et al. (2002) applied ratio analysis to Asian container seaports and concluded that the size of a port or terminal closely correlates with its efficiency and that some support exists for the claim that the transformation of ownership from public to private sector improves efficiency.

2.3.2 Panel Data Models

2.3.2.1 Studies applied in Western Seaports

All the studies outlined above share the common property that only DEA approaches for analysing cross-sectional data, rather than panel data, are used. This is despite the fact that panel data have occasionally been utilised within these studies (e.g., Martinez-Budria et al., 1999). In such cases, although panel data have been collected, in the ensuing analysis it is only treated as if it is actually cross-sectional data (i.e. dynamic time-based changes in relative efficiency levels have not been explicitly investigated or isolated).

Barros (2003b) analysed the total productivity change in the Portuguese seaports using Malmquist index model in two stages, whereas, in the first stage applied Malmquist index is estimated and followed by Tobit regression estimation in the second stage.

Estache et al. (2001) estimated the efficiency of 11 Mexican container seaports applying SFA models, Cobb-Douglas and a translog function, for the period of 1996-

1999, using two inputs and one output. The main conclusion was that the efficiency has gradually increased and ranking the performance has encouraged the competition between these seaports.

Coto-Millan & Rodriguez-Alvarez (2000) applied SFA model to evaluate the efficiency of 27 Spanish seaports using the number of twenty-foot -container equivalent units handled per berth hour, and total number of containers handled per year as outputs. They assumed that the volume of merchandise handled must be considered as output.

Barros (2005) analysed the technical change and technical efficiency in Portuguese seaport for the years 1990 to 2000, using SFA. The results showed that the average score of inefficiency was 39.6%, denoting a high degree of waste in the use of resources, despite the fact that technical change has contributed to a reduction of costs.

Barros (2006) evaluated the performance of 24 Italian seaports for the period of 2002 to 2003 using DEA with CCR and BCC models. The outputs measured were liquid bulk, solid bulk, number of containers, number of ships, and total receipt, while the inputs measured were number of personnel, the capital invested, and the value of operational costs. The general estimation showed that the Italian companies displayed high management skills and most of them were Variable Return to Scale (VRS)-efficient.

Cullinane et al. (2004) applied window analysis in order to evaluate the efficiency score of the world's major container seaports over time using 1992-1999 panel data and 20003 cross-section data. They concluded that the cross-section method is poor as it does not provide details of port performance, whereas the panel data with window analysis reflects a variation of the absolute performance of a port over time, and the relative performance of that port in comparison to the others at the same time.

Barros & Manolis (2004) applied DEA models to estimate the relative efficiency of a sample of Portuguese and Greek seaports. The purpose of this exercise is to facilitate benchmarking so that areas for improvement of management practices and strategies could be identified in the context of European seaports policy. Scale efficiency recommends that the overarching goal for seaports under consideration and privatization has been advocated as the most appropriate method to achieve economic efficiency. The comparison shows that majority of the seaports are efficient.

With regard to the applications of SFA to the port industry, Liu (1995) sets out to test the hypothesis which public sector seaports are less efficient than those in the private-sector. A set of panel data relating to the outputs and inputs of 28 commercially important UK seaports over the period of 1983 to 1990 was collected for analysis. The results failed to identify ownership as a significant factor in production and the evidence implied no clear-cut efficiency advantage for any particular form of ownership.

Cullinane et al (2004, 2005) applied alternative DEA panel data approaches to derive the efficiency of European container seaports. In doing so, the development of the efficiency of each container port in the sample can be tracked over time and, in consequence, the efficiency results are ostensibly more convincing.

Tongzon & Heng (2005) applied SFA model proposed by Battese and Coelli in 1995, using panel data of 1995-1997 to investigate the quantitative relationship between port ownership structure and port efficiency based on selected container terminals around the world. They found that the private port sector is useful to improve the operation of efficiency while the efficiency is an important indicator for the competition in this sector.

2.3.2.2 Studies applied in Eastern Seaports

Chung & Hwang (2005) applied DEA window analysis CCR and BCC models for five public bulk-shipping firms of Taiwan, called as M, N, S, E and L for the years 1999 to 2001 and used the number of employee, total assets and bulk carriers as inputs while shipping revenues as outputs. They found that L firm performs the best, followed by the firms S and E under CCR while firm L performs the best followed by the firms M and S under BCC.

Cullinane et al. (2002) analyzed the administrative and ownership structure to estimate the relative efficiency of Major Container Terminals in Asia, applying SFA with cross-section data and panel data. They conclude that the size of a port or terminal is closely correlated with its efficiency and that some supports exist for the claim that the transformation of ownership from public to private sector improves the economic efficiency. Cullinane & Song (2003) assessed the success achieved by Korean port privatisation policies in increasing the efficiency of its container terminals. They justify using the SFA model as the chosen methodology for estimating productive efficiency levels and applied this methodology to cross-sectional data under variety of distributional assumptions. These authors also used the panel data model and provide a clear distinction between productivity and efficiency measurement.

Lee (2005) dealt with 6 Malaysian container seaports with cross sectional data for the year 2003 as well as panel data for the years 2000 to 2003. The study shows that these seaports on average are sufficient to support the market demand.

The sample size of container seaports used is small in relation with number of inputs and output (Cooper et al., 2000).

Itoh (2002) analysed efficiency changes of eight international container seaports in Japan, during the period of 1990-1999 with DEA window analysis. He found that Tokyo attained high efficiency score under CCR compared to other seaports owing to the operational scale of this port.

For the purpose of comparisons, only data at the level of the container terminals should be considered rather than the entire port activity (Goss, 1990; Heaver, 1995; Alderton, 1999; Heaver et al. 2000; Heaver et al. 2001). These papers focus on measuring the efficiency of container terminals in Europe using the Data Envelopment Analysis (DEA) approach. More information on this aspect is given in *Tables* 2.4, 2.5, 2.6, and 2.7 based on geographical loction.

Table 2.3: Summary of Performance Indicators Suggested by UNCTAD.

Financial indicators	Tonnage worked Berth occupancy revenue per ton of cargo Cargo handling revenue per ton of cargo Labour expenditure Capital equipment expenditure per ton of cargo Contribution per ton of cargo Total contribution
Operational indicators	Late arrival Waiting time Service time Turn-around time Tonnage per ship Fraction of time berthed ships worked Number of gangs employed per ship per shift Tons per ship-hour in port Tons per ship-hour at berth Tons per gang hours Fraction of time gangs idle

Table 2.4: Summary of Papers Using Efficiency of Western Seaports with Cross-section data.

Papers	Method	Units	Inputs	Output
Roll & Hayuth (1993)	To theoretically rate the efficiency of seaports DEA–CCR Model Cross-section data	Hypothetical Numerical use 20 seaports	Manpower, Capital, Cargo uniformity	Cargo throughput, level service, consumer satisfaction, ship calls
Valentine & Gray (2002)	DEA-CCR Cross-section data	On North America and Europe seaports for the year 1998	Total length of berth, container berth length	Number of containers, total tons throughout
Ashar (1997)	Cost Functin	13 Terminals in Caribbean /South Atlantic region	Containet Handling	Terminal productivity
Bendall & Stent (1987)	Cost Function	Ships Companies	Cargo handling	Terminal productivity
Tabernacle (1995)	learning concepts to quayside container cranes	4 seaports	number of containers moved and unloading time	Crane performance
Tongzon (1995)	DEA method	16 selected international seaports	Terminal quay length, number of quay cranes,	Container throughput
Valentine & Gray (2001)	DEA-CCR Cross-section data	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 Cross-section data	5 Portuguese seaseaports, 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 (2005)	Stochastic Translog Cost frontier	10 Portuguese seaports for 1999-2000	Price of labour, price of capital, ships, cargo	Total cost
Cullinane et al. (2005)	DEA-CCR and BCC And FHD models Cross-section data	57 international CT seaports in 2001	Container throughput	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries
Tongzon & Heng (2005)	Stochastic Cobb-Douglas model and a competitiveness regression. Cross-section data	25 international CT 1995, 1997	Terminal quay length, number of quay cranes, port size	Container throughput
Cullinane et al. (2006)	Stochastic Cobb-Douglas and DEA models. Cross-section data	28 international CT for 2001	Container throughput	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries
Wang et al. (2003)	DEA-CCR and BCC And FHD models Cross-section data	30 international CT seaports in 2001	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries	Container throughput
Lin & Tseng (2005)	DEA-CCR, DEA-BCC, and SFA (Cobb-Douglas and Translog function) models.Cross-section Data	27 international container seaports for the years 1999-2002	Terminal length, terminal area, yard gantry and stevedoring equipment	Container throughput
Notteboom et al. (2000)	Monte-Carlo approximation of SAF model	36 European container terminals for 1994	Number of cranes, Lobours	Container throughput

Table 2.5: Summary of Papers Using Efficiency of Eastern Seaports with Cross-section data.

Papers	Method	Units	Inputs	Output
Park & De(2004)	DEA-CCR and BCC	11 Korean seaports for 2001	Berthing capacity, ships calls, Cargo handling(ton)	Cargo throughput, ships calls, revenue and consumer satisfaction
Tongzon (2001)	DEA-CCR additive Model. Cross-section data	4 Australian and 12 other international, Asian (Yokohama, Osaka seaports for 1996	Number of cranes, number of container berth, number of tugs, terminal area, delay time, labour	Cargo throughput, ship work rate
Valentine & Gray (2001)	DEA-CCR Cross-section data	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

Table 2.6: Summary of Papers Using Efficiency of Western Seaports with Panel data.

Papers	Method	Units	Inputs	Output
Barros (2003b)	DEA-Malmquist index and a Tobit model Panel data	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
Borros & Manolis (2004)	DEA-CCR and BCC Panel data	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	number of labour, capital invested, operation cost	Total cost
Barros (2006)	DEA Malmquist	24 Italian seaports for 2002-2003	Price of labour, price of capital	Cargo and container
Coto-Millán & Rodriguez-Alvarez (2000)	Translog Cost model Panel data	27 Spanish Seaports 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)
Estache & Trujillo (2001)	Translog and Cobb-Douglas production frontier model Panel data	14 Mexican seaports for 1996 to 1999	Containers handled (tons)	Volume of merchandise handled
Cullinane et al. (2004)	DEA window analysis	World's major seaports for 1992-1999	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries	Container throughput
Liu (1995)	Translog production function Panel data	28 British port authorities for 1983 to 1990	Movement of freight (ton)	Turnover
Tongzon & Heng (2005)	Applied SAF proposed by Battese and Coelli in 1995	A set of terminals around the world for 1995-1997	Quay cranes, quay length, area	Container throughput

Table 2.7: Summary of Papers Using Efficiency of Eastern Seaports with Panel data.

Papers	Method	Units	Inputs	Output
Cullinane et al., (2002)	Stochastic Cobb-Douglas production frontier :half normal, exponential, truncated models Panel data	15 Asian container seaports observed for 1989 to 1998	Number of employees	Annual container throughput in TEUs
Chung & Hwang (2005)	DEA window analysis	5 Public firms in Taiwan for 1999t0 2001	Number of employees, total assets, bulk carriers	Ship ping revues
Itoh (2002)	DEA window analysis	8 seaports in Japan for 1990-1999	Terminal length, terminal area, quayside gantry and Labor	Container throughput
Lee (2005)	DEA window analysis	6 Malaysian seaports for 2000-2003	Terminal length, terminal area, quayside gantry	Container throughput

2.4 The Fundamental Concepts of DEA

Data Envelopment Analysis (DEA) is a non-parametric method based on application of linear programming for measuring the efficiency of units which are referred to Decision-Making Units (DMUs). The fundamental concept of DEA can be traced back to Farrel (1957), who described the techniques of frontier analysis. Charnes et al. (1978) improved the DEA-CCR model and introduced the DEA as a multi-factor productivity analysis module for measuring the relative efficiencies of a homogenous set of decision making units (DMUs) (Charnes et al., 1994).

Data Envelopment Analysis (DEA) is recently increasing in importance as a tool for evaluating the performance and efficiency. Data Envelopment Analysis (DEA) is a popular method for calculating the relative efficiency of various industries (e.g. Banks branches, government agencies, Hospitals, transport sector and educational institutions (Charnes et al., 1994). More detailed reviews of the methodologies are presented (Seiford & Thrall, 1990; Ali & Seiford, 1993; Grifell & Lovell, 1994; Charnes et al., 1995; Seiford, 1990).

The DEA-technique requires a large number of medium-sized linear programming problems to be solved. The principle of this non parametrics method constitutes two important set of single/multiple variable (s) called input (s) and