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An assessment of container terminal efficiency in East Africa ports using data envelopment analysis (DEA): the case of Dar es Salaam & Mombasa ports

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AN ASSESSMENT OF CONTAINER TERMINAL EFFICIENCY IN EAST AFRICA PORTS USING DATA ENVELOPMENT ANALYSIS (DEA)

The Case of Dar Es Salaam & Mombasa Ports

By

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A dissertation submitted to the World Maritime University in partial fulfilment of the requirement for the award of the degree of

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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(Date): **24th September, 2019**

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Abstract

Title of Dissertation: An Assessment of Container Terminal Efficiency in East Africa Ports Using Data Envelopment Analysis (DEA)_ *The Case of Dar Es Salaam & Mombasa Ports*

Degree: Master of Science in Maritime Affairs (*Port Management*)

This study assesses efficiency of the dedicated container terminals in major East African ports using Data Envelopment Analysis (DEA). The study also analyses operational scale of container terminals in East Africa ports in order to establish whether or not the production size is adequate/appropriate, prior to expansion of the port capacity. Findings of this study show that despite the container terminal in Dar es Salaam port being relatively smaller compared to Mombasa port; both present equal technical efficiency scores of 1. The implication of findings with respect to selection of a potential container transhipment hub for East Africa has led to recommend a coopetition arrangement. This will not only serve as a strategy to attract more container throughput in the East African region, but also reduce logistics and supply chain management costs that could possibly upsurge from fierce competition between the two on the same potential demand of container traffic. Recommended "coopetition strategy" is expected to provide more synergies in terms of logistics cost savings as opposed to current practice of fierce competition. Although excess capacity of terminals could be considered as an operational necessity under competition; but technically such practice may result in unnecessary over investment of capital. All in all, some form of collaboration between container terminals of Dar Es Salaam and Mombasa Ports is expected to work better than fierce competition in terms of undertaking optimal infrastructure and substructure investment. Unless the current competition practices are cautiously effected, they are more likely going to increase logistics costs and consequently be harmful for economic development of the East African region and hinterland countries

KEYWORDS: Data Envelopment Analysis (DEA), Technical Efficiency, East African Ports, Container Terminal, Coopetition strategy

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List of Abbreviations

AfDB – African Development Bank

BCC – Banker, Charnes and Cooper DEA Model

CCR – Charnes, Cooper and Rhode DEA Model

CRS – Constant Return to Scale

DEA – Data Envelopment Analysis

DMU – Decision Making Unit

DRC – Democratic Republic of Congo

DSM – Dar Es Salaam

ISCOS – Intergovernmental Standing Committee on Shipping

KPA – Kenya Ports Authority

KSAA – Kenya Ships Agents Association

LPM – Linear Programming Model

OR – Operations Research

PCA – Principal Component Analysis

PwC – PricewaterhouseCoopers

SSA – Sub Saharan Africa

SFA – Stochastic Frontier Analysis

TE – Technical Efficiency

TEUs – Twenty-Foot Equivalent Units

TICTS – Tanzania International

TMEA – Trade Mark East Africa

UNCTAD – United Nations Conference for Trade & Development

VRS – Variable Return to Scale

WB – World Bank

CHAPTER 1

1.0 INTRODUCTION

Ports' efficiency has become an increasingly important subject of discussion as their terminal play a significant role of connecting links between different transport modes in the global logistics chain. In additional to essential role of ports in the international trade network; efficiency of their terminals (and in particular specialized container terminals) is equally a strategic issue for national port authorities due to the growing competition among ports and terminals around the World (Kutin *et. al.*, 2017).

On the one hand, maritime transport has been fundamental for international trade and has made container ports to become important nodes in the transport supply chain, as they bridge supply and demand for containerized goods. This move has allowed the transport of large quantities of goods by sea at reasonable costs, therefore making container ports to become super-efficient and more competitive with regards to costs and services. On the other hand, containerization and container transportation has led to increased competition between ports worldwide. Nowadays, hinterlands have become more shared due to the better efficiency of ports and increased hinterland connectivity facilitated by containerization and multi-modalism. The result of this intense inter-port competition in the container port sector is the interest in efficiency analysis by port operators (Cullinane and Wang, 2007; Dyck, 2015; Kalgora *et. al.*, 2019)

Understanding performance is a fundamental requirement to any business, whether it is the measuring of achievements against set goals and objectives or, against the competition. Ports are no exception and it is only by comparison that performance can be evaluated. Ports are, however, a complex business with many different sources of inputs and outputs, which make direct comparison among apparently homogeneous ports seem difficult. The subject is further complicated by the various types of port ownership and organizational structures that exist throughout the world (Valentine and Gray, 2001)

Essentially, position of ports in the logistics chain greatly affects the level of their efficiency and consequently nation's productivity and competitiveness (Wu and Goh, 2010). Traditionally, ports have been perceived as monopolistic due to their exclusive and immovable geographic locations, as well as, unavoidable concentration of port traffic. However, the evolution of international container and intermodal transportation has considerably changed the market structure of port from monopoly to competitive (Cullinance and Wang, 2007)

Nonetheless, according to Farrell (1957), the problem of measuring the productive efficiency of an industry (such as a port) is important to both economic theorists and policy makers. If the theoretical arguments as to the relative efficiency of different economic systems are to be subjected to empirical testing, it is essential to be able to make some actual measurements of efficiency. Importantly, if economic planning is to concern itself with particular industries, it is important to know how far a given industry can be expected to increase its output by simply increasing its efficiency, without absorbing further resources. (van Dyck, 2015).

Over the years, the port industry has witnessed a major growth across Africa; partly due to the expansion of container operations. To this effect, a number of African ports have undergone restructuring and reform processes in recent years. These processes have been mainly centred on allowing more private sector involvement in the port sector to generate investment for port development and to increase the capacities and efficiencies of ports. The ongoing port development in the Africa region has been directed towards attaining hub port status. Despite the aforementioned initiatives, African ports have been noted to be highly congested and inefficient as compared with ports in Europe and Asia (African Development Bank – AfDB Report, 2010).

Between 2005 and 2015, the countries of Sub-Saharan Africa displayed strong and consistent economic performances, averaging a gross domestic product (GDP) growth of

5 percent per year, despite the global financial crisis experienced in 2008. Specifically, freight volumes in East and Southern Africa have been rising at 9% per year through a number of vital gateway ports, with cargo transit to landlocked countries expanding at 16.5%. Against this background, many of the existing ports have struggled to meet the challenge of current and projected growth over the next 20–30 years (World Bank, 2019).

1.1 Problem (Motivational) Statement

Having worked as the middle level staff in port authority for 3 years (2011 – 2013) and later as port regulator for 5 years (2014 – 2018), I have noted that decision makers at the senior management level tend to prefer the expansion of port infrastructure and procurement of port facilities as the most probable approach to enhance port efficiency and therefore increase throughput. This is partly because of inadequate information on the root causes of observed inefficiencies

East Africa is among the region in the world with highest transport logistics costs. Notably, freight logistics costs per kilometre is of more than 50% higher than USA and Europe. These costs seriously eat away at the region's competitiveness and consequently the cost of living. It is also estimated that land-linked countries' transport costs can be as high as 75% of the value of exports. In the end, it is the producer, a farmer or a business that pays. Previous studies have established that these high transport costs reduce growth rates by 1% per annum and account for 40% of higher consumer prices across East Africa and its neighbours, affecting a consumer base of more than 250 millions of people (TradeMark East Africa – TMEA, 2014).

Terminals of major seaports in East Africa are characterized by spatial and operational inefficiency, a lack of specialist terminal operators and modern technology, a display limited functional integration, and suffer restrictions on maritime and landside access. The result in many cases has been, among other things, high ship waiting times, high berth occupancies, and congestion on both the land and maritime sides, all contributing to increased costs. Addressing these issues in the right manner could deliver both increased efficiency and capacity at lower cost, thereby obviating the immediate need for significant capital investment, and potentially reducing the scale of the required public investment. More importantly, greater efficiency raises the attractiveness of a port relative to its competitors (World Bank, 2019).

The East Africa ports' Authorities response to the above mentioned pressures, has seen to either implementing or planning capacity enhancements, relying primarily on public funds and loans. Along with proposals for modernizing existing ports, there are plans and implementation at various stages to develop new "greenfield" ports at Lamu in Kenya and Bagamoyo in Tanzania. While projected demand growth appears to support the proposed enhancements in maritime capacity, there is concern that there is insufficient focus on other key challenges facing the port sector. Thus, there is a need to improve spatial and operational efficiency, introduce modern information technology systems, attract and retain specialist terminal operators, reduce the burden on the public purse through partnerships with the private sector, and improve functional integration in the logistics chain. There is a related concern that justification for some of the investment plans is an aspiration to develop as major regional hubs serving the sub-regional network of feeder ports with an expanded hinterland and attracting more transhipment. However, not every port will be able to develop into such a role, and some are likely to be deceived in their ambitions (World Bank, 2019).

Despite an increasing number of studies on the efficiency of container terminals, their focus has mostly been on advanced and emerging markets. There are limited studies on container terminals in developing countries (Almawsheki and Shah, 2015). To my knowledge, very few empirical studies have been undertaken to determine the relative efficiency of container terminals of the major ports in Africa. Nonetheless, there is no empirical study (specifically) on container terminal efficiency employing Data Envelopment Analysis (DEA) for ports located in the Eastern and Southern of Sub-Sahara

Africa. This study fills the gap with a view to add value to the existing debate in literature by empirically assessing relative efficiencies of the major East African ports (of Mombasa, Kenya and Dar es Salaam, Tanzania) by using the DEA method.

1.2 Objective of the Study

The objective of the study is to compare container terminals of major ports along the East African coastline in terms of efficiency measures with the view to estimate existing levels of (in)efficiencies and possibly draw best practices from which the performance of could be improved in the context of regional port operating environment. Specifically, the DEA approach is used to measure technical efficiency, and slack variable analysis identifies potential areas of improvement for inefficient terminals.

Furthermore, the study analyses the operational scale of container terminals in East Africa ports in order to identify whether or not the production size is adequate/appropriate, prior to expansion of port capacity. The study results will serve as a practical decision tool to ports' users, regulators, and operators who will be keen to assess inter-port competition in the container port sector in terms of efficiency and its implications on maritime transport & logistics costs; thus making informed decisions on port choice, planning and operations.

To this end, DEA is more preferable in measuring the operational efficiency of container terminals over other alternative techniques, such as the Cobb–Douglas functions and analytic hierarchy process, because it reflects the multiple aspects of organisational performances, does not require a priori weights of performance measures and provides valuable insights into how operational efficiency can be improved. DEA is used to essentially determine the following: the best practice Decision Making Unit (DMU) that uses the least resources to provide its products or services at or above the quality standard of other DMUs; the less efficient DMUs compared to the best practice DMU; the amount of excess resources used by each of the less efficient DMUs; the amount of excess capacity or ability to increase outputs for less efficient DMUs without requiring added resources (Min and Park, 2004).

It is worth noting that, there are no kinds of cargo that traditional ports do not handle. However, container terminals of the ports get most of the attention nowadays and the bigger part of the port area is where containers are being handled (Brodin, 2010). Despite having both dedicated container berths/terminals and non-containerised in the study East Africa ports, the focus is on analysis of dedicated container terminals. This is due to the following key dual reasons: Firstly, in container terminals it is where we see the most growth worldwide in terms of throughput and investments. Secondly, in comparative unit of analysis with the view to enhance and possibly ensure uniformity/homogeneousness. In so doing, this will do away with DEA shortcomings of measuring the efficiency of the production system with given independent subsystems (Yang, *et. al.*, 200)

To the above regards, results/findings of the study should not be considered as an overall representative of the respective ports efficiency with regard to the handling of other types of cargo such as Roll-on and Roll-off, Dry Bulk and Liquid Bulk. All in all, this paper seeks to answer the following questions:

- Which port's container terminal is the most efficient in East African region?
- Is the current production size adequate/appropriate, prior to expansion of port terminal's capacity?
- What implications do the container terminals' efficiency have in maritime transport & logistics costs, as well as, the economic growth in East African regions?
- What lessons could be drawn/learnt by inefficient port terminal from observed best practices implemented by peer container terminals of ports within the region?

1.3 Significance of the Study

Vessel size increase and Liner shipping alliances have made the relationship between container shipping lines and ports more complex and have triggered new dynamics; whereby shipping lines have greater bargaining power and influence. Vessel upsizing and the rise of mega alliances have heightened the requirements for ports to adapt. While liner shipping networks seem to have benefited from efficiency gains arising from consolidation and alliance restructuring, the benefits for ports have not evolved at the same pace. To this regard, seaport authorities have increasingly been under pressure to improve efficiency by ensuring that services are provided on an internationally competitive basis. The efficiency of ports is considered to an indicator of a country's economic development, and thus monitoring and comparing one port with other ports in terms of their efficiency has become an essential part of microeconomic reform programmes in many countries (Liu, 2008; Jiang and Li, 2009; Almawsheki and Shah, 2015; UNCTAD, 2018).

Studies have established that around 80% of seaborne cargo is moved in containers; which confirms the importance of maritime trade by containers. Therefore, improvements in the efficiency of container ports are needed. Not only efficiency plays a key role in container port competition, but also an efficient operational system can help significantly in making the best use of container port resources and infrastructure, and therefore, the analysis of container port efficiency is important for the survival and competitiveness of the industry (Cullinane and Wang, 2006; Ramani, 1996; Vacca et al., 2010; Tongzon and Heng, 2005; Luo et al., 2012; Yuen et al., 2013, Cho, 2014; Almawsheki and Shah, 2015).

Additionally, the maritime transport infrastructure has strategic importance in line with market access services, global production, and trade competitiveness, economic development and social progress. Seaports being an important node in the supply chain, their performance has a bearing on transport costs and therefore, it is worth noting that port efficiency is of more significant in Economic Growth and Poverty Reduction. Long waiting times for ships have often been attributed to inadequate port infrastructure and superstructure capacity but this may not always be the case. The problem may be more of underutilization of the existing capacity rather than inadequate capacity. Although, under competition, excess capacity is seen as an operational necessity, it may result in unnecessary tied-up capital, which, in principle, is unhealthy for economic development of developing countries (Sànchez *et al*, 2003; Haralambides *et al*, 2011; Kalgora et. al., 2019).

The ports of Dar-es-Salaam and Mombasa are critical and a lifeline to the development of economies in the East African region and their need to offer efficient transport logistics services cannot be over emphasised. The ports serve Tanzania and Kenya, as well as land-linked developing economies in the hinterland of Burundi, Rwanda, South Sudan, Uganda, Zambia, Democratic Republic of Congo (DRC) and Malawi. The ports link transit countries through an inter-modal system of roads, railways and inland waterways. It is estimated that 98 % of East Africa's trade is carried through the transport corridors namely: Northern and Central corridors whereby Mombasa port and Dar es Salaam ports are respectively serving as Gateways. The Northern corridor handles 73% of the region's trade from the port Mombasa in Kenya through Uganda, to Rwanda, Burundi and DRC, with spurs to South Sudan and Ethiopia; whereas the Central Corridor carries 25% of the region's trade from the port of Dar es Salaam to Rwanda, Burundi and the Great lakes region. Therefore, the region requires an efficient transport logistics system which is predictable, reliable, transparent and guarantee back to back fluidity in the movement of cargo from seaborne to land-linked developing countries in the hinterland and vice versa. This would help in greatly in reducing the cost of doing business and reduction in firms carrying higher stock levels which ties down much needed liquidity (TMEA, 2014; ISCOS Secretariat, 2014)

The Measurement and analysis of port efficiency in East Africa will be of paramount importance to port users in gauging performance comparisons and provide regional and national port operators/regulators with an important management decision tool in addressing infrastructure gaps and high transport costs as part of critical factors hindering growth and poverty reduction in the region. Although an efficient and low-cost transport system will not guarantee export success, it is a prerequisite for African countries to become competitive in the global market. As such, there has been renewed interest in understanding the nature of constraints that freight costs impose on trade, investment, and growth (AfDB, 2010 and PwC, 2018). In the above context, analysis on port efficiency of seaport/terminal provide a powerful management tool for container port operators. It also constitutes important input for informing regional and national port (container terminal) planning and operations (Verhoeven, 2010; Almawsheki and Shah, 2015).

1.4 Organization of the Report

The rest of this paper is organized as follows: Literature review on port (container terminal) is presented in Chapter 2. Methodology of the study is covered under Chapter 3; whereas Data analysis, Findings & Discussion is presented in Chapter 4; and lastly, Conclusion and Recommendations are in Chapter 5.

CHAPTER TWO

2.0 LITERATURE REVIEW

A study of the efficiency of the port sector first appeared in academic journals in 1993, reported by Roll and Hayuth (1993) who used DEA to assess the efficiency of 20 ports with a view that DEA efficiency ratings can be a useful tool for port managers and for researchers, providing a deeper insight into port performance. The weaknesses can be detected, and therefore lead the way to potential improvements. Since then there has been a good number of studies on port efficiency, demonstrating a growing interest in methods (including the use of DEA) to measure their efficiency (Panayides *et. al*., 2008 Pallis *et. al*., 2011 Almawsheki and Shah, 2015).

Almawsheki and Shah (2015) reported that many authors have reviewed the literature for the measurement of ports efficiency and the most thorough reviews of studies focusing on the efficiency of ports are found in Odeck and Bråthen (2012), Pallis et al. (2011), Panayides et al. (2009), and González and Trujillo (2009). In fact, empirical estimations of port efficiency differ across many factors, including the method used for measuring efficiency, the type of data (inputs/outputs variables) and the region or country in which ports are located (Odeck and Bråthen, 2012). Table 1 below presents a summary of selected studies with a particular focus on measuring Port/Container Terminal/Port Authorities efficiencies using DEA.

Table 1: Summary of Selected Studies on Measuring the Efficiency of Port/Container Terminal/Port Authorities using DEA

Author	Data Type, Ports, Period	Variables (Inputs & Outputs)
Roll and Hayuth (1993)	Fictitious and Cross-sectional; Compares performance of Hypothetical numerical example 20 ports as representative of Entire World (*Authors relied on data commonly available from annual reports in ports*)	*Output:* Cargo Throughput, Service Level, User Satisfaction, Ship Calls *Inputs:* Manpower, Capital, Cargo Uniformity
Martinez-Budria *et. al*. (1999)	Panel, Evolution in efficiency levels to all (26) Spanish Ports Authorities, 1993 - 1997	*Output:* Total Cargo Moves through Dock, Revenue obtained from Rental of Port Facilities *Inputs:* Labour Expenditure, Depreciation Charges, Other Expenditures
Tongzon (2001)	Cross-sectional, 16 ports (Australia and Around the World); 1996	*Output:* Ship Working Rate, Number of Containers *Inputs:* Number Cranes, Number of Berths, Number of Tugs, Terminal Area, Delay Time, Employees
Valentine and Gray (2001, 2002)	Cross-sectional, 21 ports as representative of Entire world,	*Output:* Total tons' throughput, Number of Containers

Author	**Data Type, Ports, Period**	**Variables (Inputs & Outputs)**
		Inputs: Total Length of the Berth, Container Berth Length
Barros (2003a, 2003b)	a) Panel; Allocative and Technical Efficiency of 5-Portuguese Port Authorities; 1999-2000 *NB: Price of Labour measured by salaries and benefits divided by the number of employees; Price of capital measured by expenditure on equipment and premises divided by the book value of physical assets*	*Output:* Ships, Movement of Freight, Gross tonnage, Market share, break-bulk cargo, Containerised cargo, Ro-Ro traffic, Dry bulk, Liquid bulk, Net income *Inputs:* Number of employees, Book value of assets
	b) Panel; 10 Portuguese seaports; 1990–2000	*Output:* Ships, movement of freight, Break-bulk cargo, Containerised freight, Solid bulk, Liquid bulk *Inputs:* Number of employees and Book value of assets
Min and Park (2003)	Time series; 11-container terminals in Korea for a period of 4-years (1999–2002)	*Output:* Cargo throughput

Author	Data Type, Ports, Period	Variables (Inputs & Outputs)
		Inputs: Total length of quay; Number of cranes; Size of yard areas; Size of labour force
Barros and Athanassiou (2004)	Balanced Panel Data; Ranks the Greek and Portuguese seaports according to their total productivity for the period 1998–2000	*Output:* 4-indicators (Ships; Movement of freight; Total cargo handled (dry and liquid cargo, unloaded and loaded); and Containers (loaded and unloaded) *Inputs: 2*-indicators (Labour, measured by the number of Workers; and Capital, measured by the Book value of assets
Cullinane and Wang (2006)	Cross-sectional; Sample of 69 Europe's Container Terminals (with annual throughput of over 10,000 TEUs distributed across 24 European Countries); 2002	*Output:* Container Throughput (TEUs) *Inputs:* Terminal Length (m); Terminal area (ha); Equipment (numbers)
Al-Eraqi *et. al.* (2007)	Panel; Ports in Middle Eastern and East African countries; 2000-2005	*The output* is measured by 2-indicators: Ship calls, and 2) Throughput (movement of

Author	Data Type, Ports, Period	Variables (Inputs & Outputs)
	East African Ports: Sudan, Eritrea, Djibouti, Kenya, and Tanzania; and *Middle Eastern Ports:* Saudi Arabia, Yemen, Oman, the United Arab Emirates, and Iran.	general cargo dry and liquids and containers) load/unload, while *The inputs* are measured by the indicators, such as berth length, storage area, and handling equipment.
Wu and Goh (2010)	Cross-sectional; Compares the efficiency of port operations in emerging markets (BRIC and the Next-11) with the more advanced markets (G7); 2005	*Output:* Number of Container (TEU) *Inputs:* Terminal Area (ha); Total Quay Length (m), Number of pieces of equipment [No. of quayside gantries, yard gantries (rail-mounted and rubber typed), and straddle carrier]
Pjevčević, *et. al.* (2012)	Panel; Analyses efficiency of five ports in Serbia (Prahovo, Smederevo, Belgrade, Novi Sad and Pančevo.); 8-year period from 2001 to 2008	*Output:* Annual Port throughput *Inputs:* Total Area of Warehouse, Quay Length, and Number of cranes
van Dyck (2015)	Panel; 6-major ports (focusing on Dedicated Container	*Output:* Container throughput

Author	Data Type, Ports, Period	Variables (Inputs & Outputs)
	Terminal) in West Africa (Ports of Tema in Ghana, Abdjani in Ivory Coast, Dakar in Senegal, Lome in Togo, Cotonou in Benin, Lagos Port Complex in Nigeria); 2006-2012	*Inputs:* Total quay length (m); Terminal area (ha); number of quayside cranes number of yard gantry cranes; number of reach stackers
Carine (2015)	Cross-sectional; Selected Major Container Ports in Sub-Saharan Africa; 2012	• Terminal area and quay length are considered as a proxy of capital • Number of quayside crane and yard equipment as a proxy of labor • Container throughput is used as the only output
Almawsheki and Shah (2015)	Cross-sectional; Evaluate the technical efficiency of 19 container terminals in the Middle Eastern region; 2012	*Output:* Throughput (TEU) *Inputs:* Terminal Area (TA); Quay Length (QL); Quay Cranes (QC); Yard Equipment (YE); Maximum Draft (MD)
Zahran *et. al.* (2017)	Cross-sectional; Sample of 18 Port Authorities operating international ports located in different world regions; 2012	***Model (1)*** *Output:* Total Revenues

Author	Data Type, Ports, Period	Variables (Inputs & Outputs)
		Inputs: Number of vessels called, Total throughput, Number of passengers ***Model (2)*** *Output:* Total revenues *Inputs:* Area of open yards, Number of Berths, Number of Cargo Handling Equipment
Kalgora *et. al.* (2019)	Panel; 5-main seaports along the West African (Port of Abidjan in Ivory Coast, Tema in Ghana, Lomé in Togo, Cotonou in Benin and the Lagos Port Complex in Nigeria); 2005-2016	*7 input variables* and *1 output variable* are selected • As for the labour inputs, Number of handling equipment's such as quayside cranes, yard gantry cranes and reach stackers, are used as proxies • Quay length, Container throughput limit, Terminal area, and Draught are selected as proxies for capital • Container throughput is used as the only output

Source: Author's Collection from Literature Review

The following sub-sections highlight the general overview of the seaborne trade with an efficiency perspective on port industry, its effects on maritime transport (logistics) cost and contribution to economic growth. Status of containerization is summarized in terms of levels of investments in container terminals infrastructures and container businesses in African ports with special attention in the East African region. Furthermore, a survey of the literature efficiency in the port sector with the view to establish the need for examining container terminals holds a particular focus on East Africa ports

2.1 Port Efficiency, Transport (Logistics) Cost and Economic Growth

Seaborne trade enables a nation to gain access to international markets to sell and source products and materials contributing to the economic development of that nation. Seaports are a crucial element in seaborne trade as they provide an interface between maritime and land transport and thus a gateway for imports and exports for a country or region. Seaports therefore influence the total logistics costs of moving goods from suppliers to end customers. Shippers choose a seaport that is embedded in a logistics pathway that minimises total logistics costs. The choice of a seaport is therefore interrelated with the choice of an ocean carrier and the quality of the hinterland transport from seaports (Layaa and Dullaert, 2014).

Transportation costs between a country and its trading partners negatively affect the volume of (international) trade between those countries. Several studies have established that the level of containerisation, volume of trade by weight and seaport efficiency contribute to reduction of maritime transportation costs (Behar and Venables, 2010; Clark *et al*, 2004).

Sànchez *et. al.* (2003) surveyed Latin America ports of shipment examined the determinants of waterborne transport costs using Principal Component Analysis (PCA), with emphasis on the efficiency at seaport level and concluded that seaport efficiency reduces costs. Meanwhile, PwC report (2018) acknowledges that good logistics infrastructure is unable to compensate for poor operating, management and processes within ports. It highlights that in many instances, advanced infrastructure requires even greater levels of process and management support to fully utilise new infrastructure and equipment efficiencies. Furthermore, PwC (2018) stresses that "the importance of port and landside transport connections for the efficient operations and productivity of ports can be appreciated by understanding the link between port efficiency and landside transport accessibility with economic growth".

2.2 Ports Industry and Trend in Sub-Sahara Africa

According to UNCTAD (2015), ports are gateways for 80% of global merchandise trade by volume and 70% by value. Sub-Sahara Africa (SSA) being an emerging market region endowed with vast natural resources and a young and growing population, must accelerate its market access and trade both across the region and with the rest of the world. This is essential to stimulate economic growth, diversify its economies, reduce the inflationary effects of weak transport and logistics infrastructure, become globally competitive, create employment and reduce poverty.

Given the important enabling role of transport infrastructure in economic development, ports infrastructure should be one of the top political priorities in SSA, as it can unlock economic growth and competitiveness. Economies of scale in accommodating larger ships, and the accompanying stevedoring efficiency, could further enhance the appeal of certain ports as premier freight import/export gateways to Africa. Special attention would therefore have to be given to ensuring a feedback loop between port efficiency, regional integration and the infrastructure capacity analysis in undertaking the market analysis (PwC, 2018).

The African Development Bank expressed its support for Africa's economic integration in its policy and strategy blueprint (2015-2023). The blueprint aims to "create larger, more attractive markets, link landlocked countries to international markets and support intra-

Africa trade". The strategy includes further improving trade and industrialisation as well as supporting ports infrastructure development. As transport corridors evolve, the need for smart, calculated investments is even more crucial. As development takes shape, certain ports will play a bigger or more dominant role than others. Ports intimately connected to the more important or faster-growing trade corridors will start to benefit from economies of scale, provided development is undertaken correctly. Raising the appeal of ports that have the ability to transfer cargo to other cost-effective and reliable modes of transport, and which have superior regional integration potential, will lead to the emergence of superior regional ports, intensifying the investment requirements at these ports (PwC, 2018).

2.3 Importance of Enhanced Port Efficiency in Africa

The transportation and logistics industry is the backbone of an economy. Freight logistics is regarded economically as a derived demand resulting from demand for other products and commodities; making industry and country competitiveness strongly dependent on an effective logistics support industry. Internationally, logistics costs as a percentage of total production costs have steadily declined over the last decade, despite supply chains being more complex and having greater flexibility to customer needs than ever (PwC, 2018).

In developing countries, and specifically in Africa, logistics costs remain high as a percentage of total production costs and limit economic growth opportunities. High transport costs add 75% to the price of African goods. Most African countries either have inadequately-developed ports, too few ports and/or no port facilities in key areas. Considering that port demand volume is expected to grow by 6-8 times by 2040, the challenge is significant. Without adequate infrastructure, Africa runs the risk of sacrificing about 2% of GDP growth per annum (World Economic Forum, 2015). Access to a port and related infrastructure and operations to cope with current demand and future growth, to reduce cost, and improve overall freight logistics efficiency and reliability, are fundamental to the region’s future success ((AfDB, 2014; PwC, 2018).

A number of scholars have agreed generally that efficiency plays a key role in container port competition and therefore, the analysis of container port efficiency is important for the survival and competitiveness of the industry. In this context, not only can such an analysis provide a powerful management tool for container port operators, it also constitutes important input for informing regional and national container port planning and operations. In spite of this an extensive review of previous studies related to container port efficiency shows that the majority of studies are focused on European, American and Asian countries, and there are limited studies that focus on Asian countries. (Tongzon and Heng, 2005; Cullinane and Wang, 2006; Verhoeven, 2010; Luo et al., 2012; Yuen et al., 2013; Almawsheki and Shah, 2015). Only two studies have focused so far on the efficiency of container terminals in the East African region, those by Al-Eraqi et al. (2008) and the World Bank (2019)

2.4 Shipping Industry Trends and Challenges facing East African Ports

One of the key challenges facing the ports around the world is the need to adapt to global trends in the shipping industry—trends that are, if anything, accelerating. Bearing the fact that the East African ports are not immune to this challenge, it is therefore important to understanding and responding to these trends, if a port is to maintain its competitiveness, let alone improve it. These trends are broadly categorized as follows (World Bank – WB, 2019):

- Changes in the pattern of ship calls (types and size of vessels, the frequency of calls, establishment of feeder services, reducing turnaround time in port, etc.)
- Changes in shipping industry structure affecting the East African port sector (economic conditions, changes in shipping line ownership and alliances, consolidation of services)

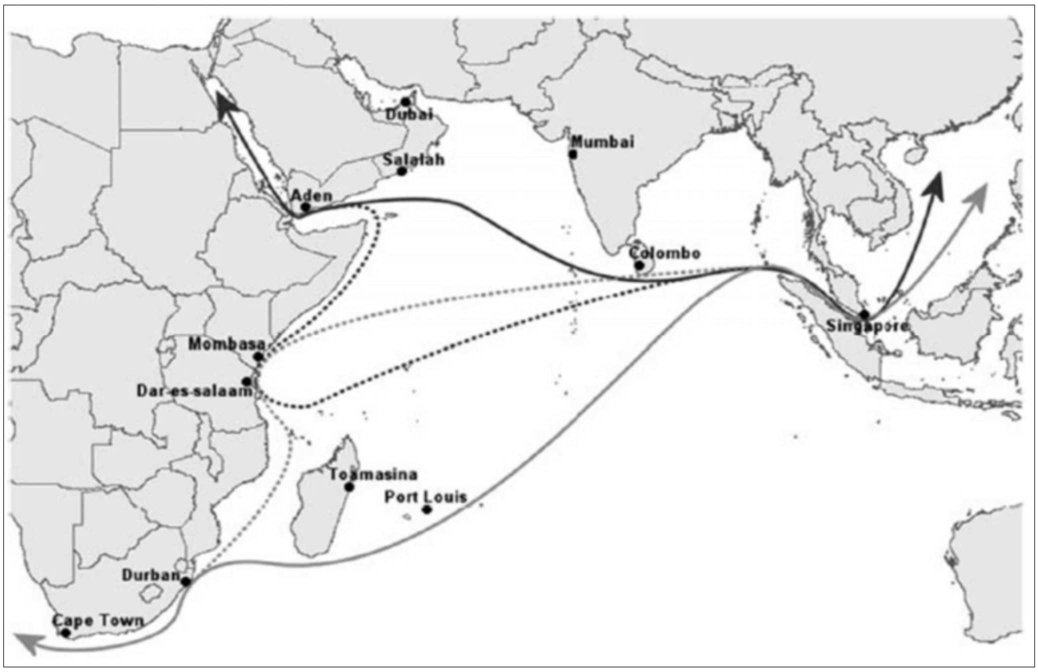
According to the World Bank – WB (2019), the primary driver underpinning these trends for all shipping lines has been the need to improve efficiency of operations and reduce costs. The higher bunker costs, which have led to slow steaming (the practice of operating cargo ships at significantly less than their maximum speed, to save fuel and reduce costs per unit) become the norm and has accelerated the movement toward improved efficiency.

Moreover, the degree of horizontal integration is less advanced in Mombasa and Dar es Salaam. In the case of Mombasa, Kenya Ports Authority (KPA) is currently developing other ports in Lamu); whereas in Dar es Salaam, Tanzania Ports Authority (TPA) is also in the process of developing a greenfield port in Bagamoyo. However, the specialization that would be expected from horizontal integration is not yet visible. Not only that, but also there is limited vertical integration in the port of East Africa; whereby the only arrangement available at Dar es Salaam port is ICDs and container freight stations (CFSs), operated by TPA and by private logistics operators. The amount of systemic organization between terminal operations and landside transport is negligible. There is also no effective gate management system. At Mombasa, logistics services are provided through a network of container depots and ICDs in Mombasa and capital city of Nairobi (World Bank – WB, 2019).

2.5 Hinterland Network and Investment of Transport Infrastructure in East African

Economically, the East African coast consists of the following major ports: Dar-es-Salaam (Tanzania), Port Louis (Mauritius), Maputo (Mozambique), Durban (South Africa), Djibouti, and Mombasa (Kenya); which are potential to become regional hub ports (***See Figure 1 below***). At present Durban (South Africa) emerges as a frontrunner in terms of size and activity. However, the successful completion of planned investment programs in these ports will determine the extent to which they are transformed into regional hubs (AfDB report, 2010).

Figure 1: Major Seaports Potentially to become East African Regional Hub Port



Source: Haralambides et. al., 2011

Politically, the East Africa region comprises the countries of Kenya, Uganda, Tanzania, Rwanda and Burundi. Kenya and Tanzania border the Indian Ocean to the East. Uganda is a land-locked country that borders Kenya to the West. The Kenya coastline is about 536 kilometres long and coast/area ratio: 3m/km^2; whereas that of Tanzania is about 1424 kilometres long and coast/area ratio: 4m/km^2 (CIA Website, 2019 and UnctadSTAT, 2017). Mombasa is the major seaport in Kenya and Dar es Salaam is the major seaport in Tanzania (however, there are several minor seaports active in this region). Mombasa port serves the hinterland comprising the countries of Kenya, Tanzania, Uganda, Rwanda, Burundi, Eastern DRC, Somalia and Sudan; whereas the hinterland served by the Dar es Salaam port includes the countries of Tanzania, Kenya, Uganda, Rwanda, Burundi, Eastern DR Congo, Malawi, Zambia and Mozambique.

Since infrastructure has a strong negative correlation with transport costs, it follows that transport costs in the sub-Saharan hinterland are lot higher than transport costs in developed countries. This, in turn, contributes to low rate of economic growth in sub-Saharan Africa. Owing to the low level of transport infrastructure investment in sub-Saharan Africa, maximum utilisation of the existing infrastructure capacity is essential before considering additional investment (Radelet and Sachs, 1998; Limao and Venables, 2001).

A seaport, being an important node in the supply chain, and its performance have a bearing on transport costs. Long waiting times for ships have often been attributed to inadequate port infrastructure and superstructure capacity but this may not always be the case, the problem may be more of underutilization of the existing capacity rather than inadequate capacity. For example, there are plans to build a new seaport at location called Mbegani in Bagamoyo district (i.e. north of Dar es Salaam) to relieve capacity demand of the seaport of Dar es Salaam. This may end up creating excess capacity. (Sànchez *et al*, 2003; Haralambides *et al*, 2011)

Although, under competition, excess capacity is seen as an operational necessity, it may result in unnecessary tied-up capital which, in principle, is unhealthy for economic development of developing countries. Full capacity utilisation in seaports in sub-Saharan Africa therefore can help increase port efficiency and thus cut down total logistics costs and hence stimulate economic growth in the region (Haralambides, 2002)

By using the seaports of Dar es Salaam and Mombasa as a case study, the objective of this dissertation is to show how measurements of relative port efficiency using DEA can offer an additional decision support tool to seaport authorities to decide whether or not additional investment in capacity is required. Bearing in mind that these seaports serve the hinterlands of developing countries, it should therefore be clear that minimization of total logistics costs is of paramount importance to the economic development of the countries.

2.6 Situational Analysis of Major Ports in East African Region

2.6.1 Port of Dar Es Salaam in Tanzania

The port of Dar es Salaam (DSM) is located in the center of Tanzania on the coast of the Indian Ocean, handling about 95% of Tanzania's international trade. Geographical position of Tanzania plays an important role in the logistic chain offering DSM Port with competitive advantage to serve a large hinterland; including the landlinked countries of Burundi, Rwanda, Malawi, Zambia, and the Democratic Republic of Congo (DRC). In terms of the typology, Dar es Salaam is considered an important regional port (**See Figure 2**). As a result, transit volumes represent approximately 35% of the total cargo throughput in the port of Dar es Salaam (Word Bank, 2019).

Figure 2: Location Map of Dar es Salaam Port

Source: World Bank (2019)

Although the aforementioned landlinked countries have a vital interest in an efficient Tanzanian port infrastructure system in order to maintain their own international trade; these countries will look into other possibilities if the Tanzanian port and transport sector falls behind its main competitors in terms of transport costs, port capacity and services. The main competitors of the port of Dar es Salaam are: Mombasa, Durban, Beira and Walvis Bay (Inros Lackner AG and Gauff Ingenieure, 2013):

Tanzania International Container Terminal services (TICTS) is operating the only specialized container Terminal in Tanzania Largest Sea Port under Lease Agreement with Tanzania Ports Authority (TPA), as the landlord. TICTS is 70 percent owned by Hutchison Port Holdings, with Harbors Investment Ltd. of Tanzania holding 30 percent. TICTS handles more than 85% of Tanzania Maritime Containerized Traffic and serves as a vital Gate way of the supply chain to and from Tanzania and the land linked countries in Eastern, Central and Southern Africa (TICTS Periodic Performance Review Report, 2018; World Bank, 2019)

TICTS is a member of Hutchison Ports, the Port and related services division of CK Hutchison Holdings Limited (CK Hutchison). Hutchison Ports is the world's leading Port Investor. Developer and operator with the network of Port Operations in 52 Ports spanning in 26 countries throughout Asia, Middle East, Africa, Europe, the Americas and Australia. TICTS was awarded a 10-year concession in 2000 to operate the Dar es Salaam container terminal, which was subsequently extended to 25 years in 2005. In 2017, the contract was renegotiated to increase and index the annual lease fee in 2018. TICTS as the leading container handling facility is committed to moving ahead and to strengthening its role as the country's premiere maritime gateway (TICTS Periodic Performance Review Report, 2018; World Bank, 2019).

2.6.2 Port of Mombasa in Kenya

Mombasa port is the Kenya's primary port and the main gateway for cargo belonging to a large hinterland including the landlinked countries of Uganda, northern Tanzania, Burundi, Rwanda, South Sudan, and the eastern regions of the Democratic Republic of Congo (**See Figure 3**). The port is connected to Mogadishu, Dar es Salaam using a regular feeder system, and transshipment hubs such as Djibouti, Durban, and Salalah. Mombasa is both a feeder port and an important regional port. The port is home to two container terminals: The Mombasa Container Terminal and the newly constructed Kipevu Container Terminal, which was commissioned in April 2016 and has an annual capacity of 550,000 TEU in Phase I. Currently, the Kenya Ports Authority (KPA) is the main operator in the port of Mombasa. It is KPA's ambition to become a landlord port authority, granting concessions to specialist private operators for all its terminals. Phase I of the new Kipevu Container Terminal has already been commissioned, but a specialist operator has not yet been contracted (World Bank, 2019).

Figure 3: Location Map of Mombasa Port

Source: World Bank (2019)

Mombasa Port has witnessed a significant increase in a number of containers handled from 1.19 million TEUs in 2017 to 1.30 million TEUs in 2018 (equal to annual growth of 9.6%); which makes it the biggest port in East Africa. In terms of container operations. The port of Mombasa is connected via “The Northern Corridor” road network to its hinterland markets, though current road conditions highlight the need for quality improvements. The recently inaugurated standard gauge railway (SGR) connects the port of Mombasa via rail to Nairobi, with plans to extend to Kisumu and Malaba, and eventually to Kampala (KPA, 2018; World Bank, 2019).

On the port efficiency side, it was reported that in 2014 users of ports reported to have lodged complaints on delays and surcharges accruing to them due to congestion caused by low productivity in the ports. Kenya Ships Agents Association (KSAA) threatened to impose Vessel Delay Surcharges on shippers due to inefficiency at the port in the months of May, June, July and August 2014, and was attributed to berth moves per hour of less than 30, the acceptable benchmark for an efficient port, low productivity of equipment, low productivity of labour forcing shipping lines to offer incentives (bribes) for work to be done. Idle ships in anchorage resulted in extra cost of fuel burnt and time lost due to unwarranted waiting time. The costs are usually passed on to shippers who are not in any way responsible for the delays. Kenya Ports Authority (KPA) being the operator of Mombasa Port, was of the view that the drawback on turnaround time was temporary and was caused by construction works of rehabilitating existing infrastructure at container terminal, expansion of exit gates and adjacent roads. It was also reported that traffic volumes at the port had increased to 122% over a period of six months against the projected 12%. The increase was mainly due to the transshipment of cargo passing through Mombasa Port. The other reason for the delays was attributed to heavy rains during the period in question (The Intergovernmental Standing Committee on Shipping – ISCOS, 2014).

To address the above experienced inefficiency, Mombasa port came-up with an ambitious plan to become the main hub for East Africa and launched expansion and investment programmes, including: Dredging of the access channel to a water depth of between 15.0 m and 17.5 m, Dredging of the Mombasa Container Terminal to the design depth of 12.6 m; Construction of Berth 19 to expand the existing container terminal; Expansion of the existing container handling equipment to handle the latest container vessels; and Developing a new container terminal with a total berth length of 900 m and a water depth of 15 m (Kenya Ports Authority – KPA, 2014). As of now, dredging is completed and Mombasa port is able to handle panamax vessels

CHAPTER THREE

3.0 METHODOLOGY

This study applies the concept of measuring efficiency whose development began with Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951) who defined a simple measure of efficiency that could account for multiple inputs. According to Barros and Athanassiou, (2004), efficiency analysis of DMUs (such as sea-ports) embraces three scientific quantitative methods, namely:

(i) Ratio analysis,
(ii) The econometric frontier (also referred as Stochastic Frontier Analysis – SFA); and
(iii) The Data Envelopment Analysis (DEA)

3.1 Concepts used in Measuring Efficiency

Modern efficiency measurement began with Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951) to define a simple measure of firm efficiency which could account for multiple inputs. Farrell (1957) proposed that the efficiency of a firm can be classified into the following three different levels (Coelli, 1996):

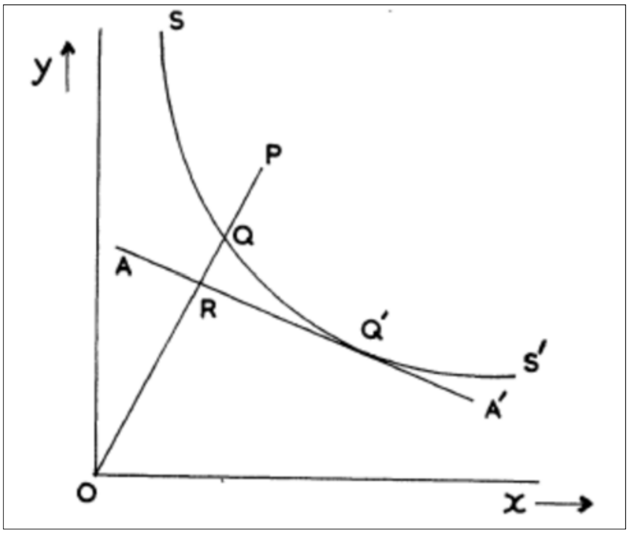
a) *Technical Efficiency (TE),* which reflects the ability of a firm to obtain maximum from a given set of inputs
b) *Allocative (Price) Efficiency (AE),* which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices
c) *Economic (Overall) Efficiency (EE)* is the product of the above two measures, which can be expressed as follows: EE = TE*AE

3.1.1 Input-Oriented and Output-Oriented Efficiency Measures

Measures of efficiency comes in two forms*: Input-Oriented* and *Output-Oriented.* On one hand, the *Input-Oriented* efficiency establish how possible it is to change input levels holding the output constant (extent to which inputs could be reduced without changing the level of output). Only interested in inputs reduction, outputs are fixed at their current levels. Conversely, in applying the *Output-Oriented* efficiency – objective is to hold input constant and try to establish how possible it is to increase output (quantify the extent to which output could be increased without necessarily have to change our inputs). Only interested in output increase, inputs are fixed at their current levels.

Under *Input-Oriented* efficiency measure, Farrell (1957) illustrated his ideas using simple case involving firms which use two inputs (X and Y) to produce a single output presented by Unit Isoquant SS', under the assumption of a known efficient production function exhibiting constant returns to scale; which permits all the relevant information to be illustrated in a simplified as Figure 4 below.

Figure 4: Technical and Allocative Efficiency from an Input-Orientation



Source: Farrell (1957)

If a given firm uses quantities of inputs, defined by point P, to produce a unit of output, the technical inefficiency of that firm could be represented by the distance QP, referring to the amount by which all inputs could be proportionally reduced without a reduction in output. Algebraically, *Technical Efficiency (TE)* is usually presented in percentage terms by the ratio *(OQ/OP)*; which is also equal to *1 – (QP/OP);* whereby *QP/OP* represents the percentage by which all inputs could be reduced. Mathematically, TE can be expressed as follows:

$$TEi = \frac{OQ}{OP} = 1 - \frac{QP}{OP} \qquad \text{..............................(1)}$$

If the input price ratio, presented by the line AA' in Figure 2 above is also known, then the Allocative Efficiency (AE) of the firm operating at R is defined to be the ratio (OR/OQ) since the distance RQ represents the production costs that could be reduced if production were to occur at the allocatively (and technically) efficient point Q' as opposed to point Q, which is technically efficient, but allocatively inefficient. Mathematically, TE can be expressed as follows:

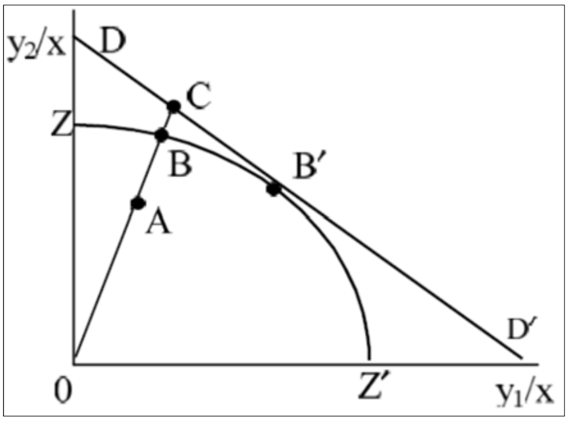
$$AEi = \frac{OR}{OQ} \text{ .... (2)}$$

Therefore, the *Economic (Overall) Efficiency (EE)*, is defined to be the ratio (OR/OP); whereby the distance RP can also be interpreted in terms of cost reduction. Note that the product of technical and allocative efficiency provides the overall economic efficiency (Coelli, 1996). Mathematically, TE can be expressed as follows:

$$EEi = (TE) * (AE) = \frac{OQ}{OP} X \frac{OR}{OQ} = \frac{OR}{OP} \text{................................ (3)}$$

Alternatively, the *Output-Orientated* efficiency measure could be used to answer the question "By how much can output level be proportionally expanded without altering the level of inputs used?". The Farrell Output-Orientation Efficiency measure is illustrated in Figure 5 below:

Figure 5: Technical and Allocative Efficiency from an Output-Orientation



Source: Coelli, T. J. (1996) – A Guide to DEA (Computer) Program

In figure 3 above, the distance AB represents technical inefficiency. This is the amount by which output levels could be increased without requiring extra inputs. Hence, the measure of output-oriented technical efficiency is the ratio (Coelli, 1996)

$$TEo = \frac{OA}{OB} \qquad (4)$$

If the price information is made available, then the isorevenue line DD' could be drawn and define the Allocative Efficiency (AE_o) to be

$$AEo = \frac{OB}{OC} \qquad (5)$$

Output-Oriented Allocative Efficiency (AE_o) has a revenue increasing interpretation (similar to the cost reduction interpretation of Allocative Efficiency in the input-oriented case). Furthermore, the overall Economic Efficiency (EE_o) can be defined as the product of the two measures above (Coelli, 1996)

$$EEo = (TEo) * (AEo) = \frac{OA}{OB} X \frac{OB}{OC} = \frac{OA}{OC} \qquad (6)$$

The choice between the two depends on the context in which one is doing the analysis. For the purpose of limiting the scope, this study focus on Output-Oriented Technical Efficiency of the firms (i.e. container terminals of the ports).

Based on Farrell's (1957) work, the measurement of efficiency and the estimation of frontiers have developed explosively over the past several decades. DEA and SFA are the two most important alternative approaches in this respect and have been extensively studied as methodologies in their own right and ubiquitously applied to an eclectic range of industrial/organisational contexts (Cullinane et. al., 2006)

Trujillo et. al. (2013) pointed out that for over the last three decades, two approaches have been developed to estimate the frontier and measure efficiency: the econometric approach, whose main example is stochastic frontiers, and the linear programming techniques, represented basically by Data Envelopment Analysis (DEA). In the general methodological literature on efficiency estimation (Banker et al., 1993; Mortimer, 2002; Mortimer and Peacock, 2002), as well as in the empirical literature on ports (Cullinane et al., 2006) there exists evidence that, when applied to the same set of data, the two approaches produce outputs, which are reasonably correlated.

3.1.2 Stochastic Frontier Analysis

Stochastic Frontier Analysis (SFA) was introduced simultaneously by Aigner et al. (1977) and Meeusen and van den Broeck (1977). It assumes that a parametric function exists between production inputs and outputs. The notable advantage of SFA is not only does it capture technical inefficiency, but also recognises the fact that random shocks outside the control of DMUs can affect output. Consequently, the essential idea behind the model is that the error term is composed of two parts; a one-sided component that captures the effects of inefficiency relative to the stochastic frontier, as well as a symmetric component that permits random variation of the frontier across DMUs, and captures the effects of measurement error, other statistical noise, and random shocks outside the control of DMUs (Cullinane *et. al.*, 2006).

Cullinane et. al. (2006) demonstrates the first step in solving a stochastic frontier model is to specify a functional form, with solutions most frequently relying upon maximum likelihood estimation. A stochastic frontier model can be expressed as Equation below, where the technical efficiency of firm k is U_k and must be positive, whereas the statistical noise component V_k can be either positive or negative.

$$Y_k = f(X_{1k}, X_{2k}, \dots X_{mk}, U_k, V_k) \quad (1)$$

The above general function form could be further expanded depending on the objective that DMU intends to fulfil (minimization or maximization), or in other words the basis of analysis (i.e. input or out oriented model) and choice of the function form. Cullinane et. al. (2006) shows that in case the output oriented model is preferred for the application of the SFA model, the estimation of relative operational efficiency of the port (container terminal) operator could be conducted by assuming the appropriateness of the log-linear Cobb–Douglas function, and could be specified in the cross-sectional case as follows:

$$In\, Y_k = \beta_0 + \beta_1 In\, Terminal\, Length_k + \beta_2 In\, Terminal\, Area_k + \beta_3 In\, Quay\, Crane_k + \beta_4 In\, Yard\, Crane_k + \beta_5 In\, Straddle\, Carrier_k + U_k - V_k) \quad (2)$$

where k represents 1,2,. . .,nth port/terminal and β_0 through β_5 are input coefficients associated with the independent variables in the model and are the object of estimation. The disturbance term Uk represents the symmetric (statistical noise) component and Vk (≥0) is the one-sided (inefficiency) component.

3.1.3 Data Envelopment Analysis

Data Envelopment Analysis (DEA), as originally proposed by Charnes, Cooper and Rhodes (CCR) (1978) as an extension of ideas of Farrell M. J. (1957); which is concerned with the estimation of technical efficiency and efficient frontier. It is a linear programing technique (i.e. “non-parametric” frontier estimation methodology and “data-oriented” approach) for evaluating relative efficiencies and performance of a collection of related comparable entities (a set of peer entities called Decision Making Units or DMUs) in transforming inputs into outputs.

DEA is a powerful quantitative tool that provides a means to obtain useful information about efficiency and performance of firms, organizations, and all sorts of functionally similar, somewhat autonomous, operating units. DEA’s domain can be any group of many entities characterized by the same set of multiple attributes, and therefore making it appropriate to measure efficiency when there are multiple inputs and outputs and there are no general acceptance weights of aggregating inputs and aggregating outputs (Yun, Nakayama & Tanino, 2004; Goksen et. al., 2015)

In general, DEA is referred to as a nonparametric technique in the sense that it does not require an assumption about a functional form of the efficient frontier and, therefore, no parameter estimation, making it useful in a wide variety of applications. DEA clusters the entities as “efficient” or “inefficient” depending on their relative geometric location with respect to an empirical efficient frontier. The comparison is strictly in relation to the members of the subject group. DEA provides decision makers with information about how well subordinate units transform the resources they manage locally into the outputs that are necessary to achieve the operation’s mission.

3.1.4 Comparison between DEA and SFA

Literature suggests two main approaches, parametric and non-parametric, for constructing efficiency frontiers using which efficiency scores of other units can be based. None of these two approaches dominates the other; each has advantages and disadvantages. Despite each having serious advocates, the use of one or the other method will depend on the concrete case of study (Raj, 2014). Trujillo *et. al.*, (2013) discussed the essential difference among these methodologies, from which their advantages and disadvantages arise, can be summarized in **Table 2** below

Table 2: Characteristics of DEA and SFA

Data Envelopment Analysis (DEA)	Stochastic Frontier Analysis (SFA)
Non-parametric approach	Parametric approach
Deterministic approach	Stochastic approach
Does not consider random noise	Consider random noise
Does not allow statistical hypothesis to be contrasted	Allow statistical hypothesis to be contrasted
Does not carry out assumptions on the distribution of inefficiency term	Carry out assumptions on the distribution of inefficiency term
Does not include error term	Includes a compound error term: One of one side and the other asymmetrical (two queues)
Does not require specifying a function form	Requires specifying a function form
Sensitive to the number of variables, measurement errors and outlier	Can confuse inefficiency with a bad specification of the model
Estimation Method: Mathematical Programing	Estimation Method: Econometric

Source: González and Trujillo (2009) as cited in Trujillo et. al. (2013)

This dissertation is concerned with the use of DEA methods (Linear Programming Models) based on the following arguments: Raj (2014) was of the view that when multiple inputs and outputs are encountered, DEA is a powerful tool used for decades in measurement of productivity/efficiency with wide range of applications. An advantage with DEA is that each relatively inefficient (less than 100% efficiency) is not just compared with one ideal DMU but is benchmarked only with units can be said to be similar to it and yet efficient and provides a path by which the relatively inefficient units can become efficient. Additionally, Raj (2014) concludes that "DEA has proved to be a very powerful tool in benchmarking DMUs. Among different standalone techniques in calculating efficiencies of DMUs, DEA is quite superior to most, if not all".

Further, Yang, et. al. (2000) pointed out that DEA is designed to identify the best practice DMU without a prior knowledge of which inputs and outputs are most important in determining an efficiency measure (i.e., score) and assess the extent of inefficiency for all other DMUs that are not regarded as the best practice DMUs. Park and De (2004) also concluded that DEA is a potentially powerful approach to the evaluation of seaports efficiency

Notwithstanding, scholars in the existing literature on applicability of SFA and DEA techniques are of the view that DEA approach appears to be most suitable for not only being non-parametric but also DEA does not require an explicit a priori determination of relationships between the inputs and outputs. In addition, DEA does require setting of rigid importance weightings for the various factors. It also has the advantage of being an objective efficiency evaluation model (Wu and Goh, 2010)

According to Panayides *et. al.* (2009) "DEA is a nonparametric method of measuring the efficiency of a Decision-Making Unit (DMU) such as a firm or a public-sector agency, first introduced into the Operations Research (OR) literature by Charnes, Cooper, and Rhodes (CCR). The decision-making units (DMUs) can be different organizations, departments or groups, all with the similar functions, goals and market segments".

3.2 Mathematical Expression of DEA Model

DEA is designed to identify the best practice DMU without a priori knowledge of which inputs and outputs are most important in determining an efficiency measure (i.e. score) and assess the extent of inefficiency for all other DMUs that are not regarded as the best practice DMUs (Panayides *et. al.*, 2009). Being non-statistical in nature, the Linear Programming solution of a DEA problem produces no standard errors and leaves no room for hypothesis testing. In DEA, any deviation from the frontier is treated as inefficiency and there is no provision for random shocks (Panayides *et. al.*, 2009)

The following model illustrates how the relative efficiency score of DMU is obtained as proposed by Charnes et. al. (1978) based on the seminar paper of Farrell (1957) and later adopted by various others (Panayides *et. al.*, 2009; van Dyck, 2015; Kalgora et. al., 2019). They suggested the following mathematical programming for estimating the relative efficiency score of a particular DMU_j among similar n entities being evaluated.

$$DMU_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_r y_{rj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_i x_{ij}} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1, \ldots, n \qquad (3)$$

$u_r, \ldots, u_s > 0$ and $v_i, \ldots, v_m \geq 0; r = 1, \ldots, s; i = 1, \ldots, m$

where:

y_{rj} = amount of output r produced by DMU_j

x_{ij} = amount of input i utilized by DMU_j

r = number of outputs generated by the DMUs

i = number of inputs used by the DMUs.

u_r = weight given by DEA to output r

v_i = weight given by DEA to input i

Converting the computations above to Linear Programming Model (LPM1):

$$max \sum_{r=1}^{s} u_r y_{r0} \tag{4}$$

$$subject\ to \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, j = 1, \dots, n \tag{5}$$

$$\sum_{i=1}^{m} v_i x_{ij} = 1$$

$$u_r, v_i \geq 0$$

As depicted by Panayides *et. al.* (2009) the problem above, known as "CCR ratio model", can be reduced and transformed to the Linear Programming Model (LPM2). The DEA model (LPM2) is formulated in the following form:

$$Max\ \Theta_p(u_r, v_i) = \sum_{r=1}^{s} u_r y_{rp} \tag{6}$$

$$subject\ to \sum_{i=1}^{m} v_i x_{ip} = 1 \tag{7}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0; j = 1, \dots, n$$

$$u_r \geq \varepsilon; i = 1, \dots, s$$

$$v_i \geq \varepsilon; i = 1, \dots, m$$

Where Θ_p is relative efficiency of p^{th} DMU

The combination of the two models (LPM1 and LPM2) results in the DEA-Charnes, Cooper and Rhode (CCR) and DEA- Banker, Charnes and Cooper (BCC) Models; whereby DEA-CCR assumes Constant Return to Scale and DEA-BCC accommodates technologies that exhibit Variable Return to Scale. By solving the above Equations, the efficiency of DMU is maximized subject to the efficiencies of all DMUs in the set with an upper bound of 1. The above model is solved n-times to evaluate the relative efficiency of each DMU; whereby the weights u_r and v_i are treated as unknown variables whose values will be optimally determined by maximising the efficiency of the targeted DMU. An efficiency score of 1 indicates that the DMU under consideration is efficient relative to other DMUs, while an efficiency score of less than 1 indicates the DMU under consideration is inefficient (Panayides *et. al.*, 2009; van Dyck, 2015).

In a broader sense, DEA converts multiple incommensurable inputs and outputs of each decision-making unit (DMU) into a scalar measure of operational efficiency, relative to its competing DMUs. Since DEA provides a relative measure, it will only differentiate the least efficient DMU from the set of all DMUs. An efficiency score represents a port authority's ability to transform a set of inputs (given resources) into a set of outputs. The above model also identifies a peer group (efficient DMU with the same weights) for the inefficient DMU. In other words, the best practice (most efficient) DMU is rated as an efficiency score of 1, whereas all other less efficient DMUs are scored somewhere between 0 and 1. (Yang, et. al. 2000, Min and Park, 2004).

CHAPTER FOUR

4.0 EMPIRICAL ANALYSIS, FINDINGS, INTEPRETATION AND DISCUSSION

This dissertation analyzes the efficiency of dedicated container terminals using the DEA model in two major ports of East African countries: Dar es Salaam port in Tanzania and Mombasa port in Kenya. Since both two ports are in the same region, a fair comparison between container terminals is achieved through almost the same economic conditions and overlapping hinterland served by the two major ports in the region.

4.1 Data Selection

Basically, a container terminal of the port depends on the efficient use of land, labour and capital (equipment), where the input data used to include the quay length (in metres), the terminal area (in hectares), the number of quayside cranes, the number of yard gantry cranes, and the number of reach stackers used in each port over a given period of study (van Dyck, 2015). Therefore, the following key variables will be of interest:

Dependent Variable: Container throughput (TEUs) and Ship Calls

Independent Variables: Quay length (m); Terminal area (sqm); Number of Ship-to-Shore (STS) Gantry cranes; Rubber Tyre Gantry (RTG) cranes; Rail Mounted Gantry (RMG) crane; Mobile Cranes; Reach Stackers; Fork Lift; Empty Handler; and Terminal Tractors

For the purpose of this research, the output variables to measure the efficiency of a port terminal are container throughput and ship calls (i.e. the quantity of goods and frequency/number of ships calls handled by the port/terminal from which it generates its main income). Container throughput is used because it is the primary source of comparison between container ports' terminals. It is also a figure used by all ports to measure the level of business transacted (Valentine and Gray, 2001).

The quay length is important in evaluating the efficiency of ports/container terminals. It is one important indicator as to the turn-around time that can be achieved by ports, since it reflects the size of a ship that can be allocated a berth at a particular point in time. As a strategy, berth availability as a function of quay length can affect the efficiency of shipping lines. In addition, the number of quay-side cranes is an important measure of productivity. This input directly affects the speed with which container ships may be served (more cranes may increase the number of containers handled per ship hour), and in effect, the turn-around time as well.

Furthermore, Pjevčević et. al. (2012) pointed out that the number of quay side cranes also increases the ability of the port by handling more vessels simultaneously. The berth length and number of quay-side cranes therefore reflect the berth-side productivity of this analysis. In the same argument made by van Dyck, (2015), terminal area, the number of yard gantry cranes, and the number of reach-stackers are used in this study because they reflect yard-side productivity has a common use within terminal areas.

Park and De (2004) presented how different studies apply different types of Labour units; which included: Size of Labour force (Roll and Hayuth, 1993), Labour expenditures (Poitras et al.,1996), Labour as number of stevedore gangs (Tongzon, 2001) and Labour in terms of number of workers (Barros, 2003; Barros and Athanassiou, 2004)

4.2 Operationalization of Variable and Empirical Analysis

The DEA model can be divided into several types depending on the nature of the applied problem and characteristics of given data. The typical basic models widely used are DEA-Constant Return to Scale (CRS) based on input and output oriented CCR model and DEA-Variable Return to Scale (VRS) based on input and output oriented BCC model (Park and Zheng, 2016). To this effect, the efficiency analysis for the proposed container terminals in this study is performed using the output oriented CCR and BCC models.

Reviewing from the previous studies, it is evident that the selected variables are highly associated with measuring of the port efficiency. The same kind of data are used in this study, which include container throughput (TEUs), Ship Calls, Quay length (m); Terminal area (SQM); Number of STS Gantry cranes, RTG cranes, RMG cranes, Mobile Cranes, Reach Stackers, Fork Lift, Empty Handler, and Terminal Tractors; all collected over an 11-year period (from 2008 to 2018).

The factors considered on selection of terminals and variables are as follows: First, the terminal should be dedicated for container handling and has already entered into a stage of the stable operations. Second, significant data should be available from official periodic performance review during the study period. Third, the total traffic volume of the terminal should account the substantial container traffic volume in the East Africa region.

Table 3 below provides an overview of the container throughput (TEUs) and Ship Calls in the above mentioned ports for the period from 2008 to 2018 as collected from KPA Annual Review and Bulletin of Statistic, TPA/TICTS Periodic Performance Reports and direct visit/contact with Terminal operator officials

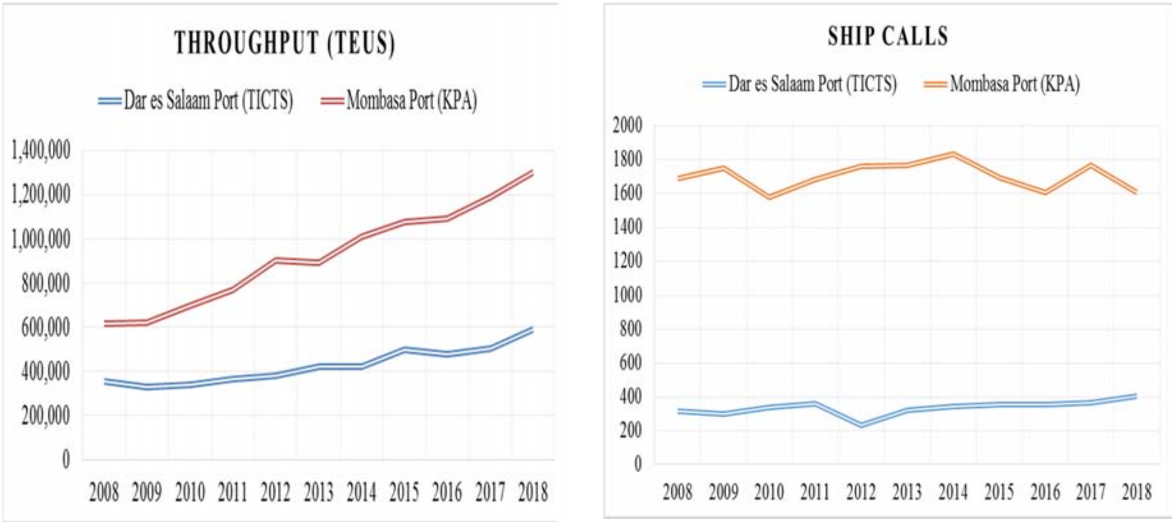
Table 3: Container Throughput (TEUs) and Ship Calls for Selected Port Terminals

Port Terminal/ Year	Dar es Salaam Port (TICTS)		Mombasa Port (KPA)	
	Throughput (TEUs)	*Ship Calls*	*Throughput (TEUs)*	*Ship Calls*
2008	356,562	319	615,733	1,686
2009	327,108	302	618,816	1,748
2010	341,948	339	695,600	1,579
2011	365,753	362	770,804	1,684
2012	381,961	235	903,463	1,763
2013	423,184	323	894,000	1,768
2014	423,553	343	1,012,002	1,832
2015	496,773	357	1,076,118	1,694
2016	480,228	355	1,091,371	1,607
2017	501,689	367	1,189,857	1,767
2018	591,772	403	1,303,862	1,605

Source: KPA Annual Performance Review and Bulletin Statistics and TICTS Periodic Performance Report

From **Figure 6** below, it can be concluded that all port terminals have been experiencing continuous increases in container throughput but registered ship calls oscillations during the study period (2008 – 2018).

Figure 6: Container Throughput and Ship Calls Trend (2008 – 2018)



Source: TICTS and KPA Periodic Performance Review Reports

It is quite clear that the container terminal at Mombasa port has both the higher throughput and ship call, but that does not automatically imply it to be superior in terms of the efficient use of available resources, unless the appropriate methodology is applied to assess relative efficiency levels. This is the basis of motivation for this study with the view to establish best practices (i.e. targeted performance benchmark or what more could be achieved from available resources), contribute to reduction of logistics cost and consequently attracting more cargo in the region.

The assessment of port efficiency using the DEA approach begins by choosing appropriate input and output variables. In this study, the following variable have been considered: Terminal quay length (m), Terminal area (sqm), Number of Ship-to-Shore (STS) Gantry cranes, Rubber Tyre Gantry (RTG) cranes, Rail Mounted Gantry (RMG) crane; Mobile Cranes, Reach Stackers, Fork Lift, Empty Handler, and Terminal Tractors. These are chosen to be input variables; while container throughput (TEUs), Number of Ship Calls per year is declared as the output variable. The overview of input and output variables per ports' container terminal and years is given in **Table 4** below.

In the process of evaluating efficiency of the port/terminal, one of the most important inputs is port infrastructures (such as quay length and terminal area). Several authors suggest that quay length is crucial to the efficiency of ports and terminals. In general, quay length differs from port to port and is designed to correspond with the anticipated size of the ships**.** Since the shipping company's main aim is to reduce the sum of the ships turnaround time, the optimum assignment of arrived ships to ports/terminals quay length becomes an important strategy, while ports, competing for the clients (shipping companies) increase their efficiency (Wu and Goh, 2010; Pjevčević et. al., 2011)

Port/Terminal operational equipment (such as the number of cranes and terminal tractors) directly influence the increase in port capacity and is therefore included in the input variables. Availability of more equipment is likely going to enhance efficiency and flexibility allowing port to work with more vessels simultaneously. Since the port facilities are very expensive, it is desirable to optimize their performance, making better management decisions. In particular, heuristics for port operations and functional and process modelling are used for scheduling loading/unloading operations by cranes in order to minimize the maximum time it takes to serve a given set of vessels. As a result of this, overall time that vessels spend in the port is less, terminals are more available for other ships and the service offered to the port's customers is improving (Gudelj, 2010; Pjevčević et. al., 2011).

Furthermore, container terminal depends crucially on the efficient use of labour. In the light of the unavailability or unreliability of direct data/information; Cullinane and Wang (2006) were of the view that labour inputs could be cautiously derived from a predetermined relationship to terminal facilities. However, it is very important to note that this predetermined relationship is not applicable to all types of ports/terminals with different characteristics of production. It is also dangerous to apply this relationship to container ports of different equipment arrangements employed. Fortuitously, container terminals in Mombasa and Dar es Salaam port have fairly similar equipment arrangements. Consequently, labour units in this particular case could be derived from a predetermined relationship to operational equipment

As far as the output variable of container terminal production is concerned, container throughput is unquestionably the most important and widely accepted indicator of container port or terminal output. The total amount of container that is being transferred within the operational shore zone during the year can be measured by container throughput in TEUs. Almost all previous studies have treated it as an output variable, because it relates closely to the need for cargo-related facilities and services and is the primary basis upon which container ports are compared, especially in assessing their relative size, investment magnitude or activity levels. Most importantly, it also forms the basis for the revenue generation of container port/terminal (Cullinane and Wang, 2006; Pjevčević et. al., 2011)

It is worth mentioning that being non-statistical in nature, the Linear Programing (LP) solution of a DEA problem produces no standard errors and leaves no room for hypothesis testing. In DEA, any deviation from the frontier is treated as inefficiency and contrary to SFA there is no provision for random shocks.

Table 4: Inputs and Output Variables for Dedicated Container Terminals of the Major Ports in East Africa

Port (Container Terminal)	Year	Inputs (Quay Length, Terminal Area, Number of Equipment)										Outputs	
		Quay Length	Terminal Area	STS	RTG	RMG	Mobile Crane	Reach Stacker	Fork Lifts	Empty Handler	Terminal Tractors	Through put	Ship Calls
Dar es Salaam	2008	725	187500	3	18	1	9	13	18	8	31	356562	319
	2009	725	187500	3	12	1	5	11	20	9	34	327108	302
	2010	725	187500	4	14	1	3	8	16	8	32	341948	339
	2011	725	187500	4	12	1	2	6	15	9	42	365753	362
	2012	725	187500	4	11	1	2	7	13	9	42	381961	235
	2013	725	187500	5	12	1	0	7	13	8	42	423184	323
	2014	725	187500	5	12	1	0	7	13	8	49	423553	343
	2015	725	187500	6	19	1	4	9	13	6	49	496773	357
	2016	725	187500	6	19	1	4	8	16	6	43	480228	355
	2017	725	187500	6	17	1	4	8	18	7	44	501689	367
	2018	725	187500	6	17	1	4	8	21	7	44	591772	403
Mombasa	2008	964	312767	4	12	2	9	7	40	3	72	615733	468
	2009	964	334667	4	12	2	7	11	45	3	71	618816	509
	2010	964	363266	4	19	2	7	12	31	3	71	695600	500
	2011	964	393421	7	22	2	7	11	29	3	80	770804	504
	2012	964	363266	7	22	2	8	19	30	3	95	903463	431
	2013	1204	423266	7	22	2	8	19	35	5	95	894000	500
	2014	1573	435872	7	34	2	8	24	27	5	99	1012002	557
	2015	1573	435872	7	34	2	10	22	33	5	99	1076118	514
	2016	1400	586802	12	38	2	14	20	41	13	99	1091371	477
	2017	1400	586802	12	38	2	16	20	43	15	88	1189857	583
	2018	1400	586802	13	50	6	18	15	48	12	101	1303862	576

Source: TPA/TICTS and KPA Periodic Performance Review Reports

4.3 Summary of Findings, Discussion and Interpretation

The output-oriented DEA-CCR, DEA-BCC and Scale efficiency models were applied for the assessment of two dedicated/specialized container terminals in major ports of East African region. Data collected for the period from 2008 to 2018 and the software developed by Coelli (1996) known as the DEAP version 2.1 is used in this analysis. The findings from the analysis are summarized in **Table 5** below.

Table 5: Results of the Empirical Analyses (2008 – 2018)

Ports, Country: Owner and Operator of Specialized Container Terminal	DEA-CCR	DEA-BCC	Scale Efficiency
Dar es Salaam Port, TANZANIA: Container terminal owned by TPA and operated by to TICTS	1.000	1.000	1.000
Mombasa Port, KENYA: Container terminal owned and operated by KPA	1.000	1.000	1.000

Source: Author

In both analyses of DEA-CCR (which assumes constant return to scale) and DEA-BCC (which assumes variable return to scale), all terminals are evaluated as efficient with score of 1. Results from DEAP software version 2.1 are attached as an appendix to this report.

Based on the results of the model, all specialized container terminals in major aforesaid East African seaports are equally efficient with a score of 1. Findings of this study show that despite container terminal in Dar es Salaam port being relatively smaller compared to Mombasa port; both present equal scores of relative technical efficiencies. This emphasizes that the size of port (bigger/small) in terms of infrastructure, operational equipment or the volume of traffic, should not be the only factor to compare performance between ports/terminals. Other operational arrangements (such as the improvement in utilization of available space and operational practices) could enhance the efficiency of ports regardless of their sizes.

Partly, the highly ranked efficiency scores of 1 may have been attributed to fierce competition between these ports for transit cargo meant for the Central, Eastern, Southern and Great Lake region of Africa. However, competition practices tend to push port authorities to consider development of terminals with excess capacity as an operational necessity. To my view, such practices may technically result to unnecessary over investment of capital and eventually become a drawback to meet an overall goal of achieving clients' satisfaction at lowest possible logistics costs.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

This dissertation measures relative efficiencies of the two dedicated/specialized container terminals in the major ports of East Africa (located in the cities of Dar Es Salaam and Mombasa). The dual ports are currently experiencing fierce competition with each pursuing to become regional hub. The Data Envelopment Analysis (DEA) which is the widely used methodology to measure the relative efficiency of Decision Making Units (DMUs) was employed in this study to compare the earmarked container terminals located at the aforementioned seaports. Moreover, the DEA is regarded as the very powerful tool that can relate multiple outputs and inputs, establish ranking and benchmarking, as long as the data are accurate, balanced, and DMUs comparable.

Panel data from 2008 to 2018 were applied to the DEA models to determine relative efficiencies over time. As argued by several scholars who happened to measure relative efficiency of the ports and terminals, panel data are the more relevant for this kind of study than cross-sectional data. The basis for this argument is that cross-sectional data are susceptible to seasonal variations in efficiency and may lead to the drawing of misleading conclusion about the efficiency of the port or terminal.

Several inputs variables were carefully selected for the analysis to ensure the availability of balanced data between the two container terminals. The author was able to gather historical balanced data for the following 10-input variables: Quay length (m), Terminal area (sqm), Number of Ship-to-Shore (STS) Gantry cranes, Rubber Tyre Gantry (RTG) cranes, Rail Mounted Gantry (RMG) crane, Mobile Cranes, Reach Stackers, Fork Lift; Empty Handler, and Terminal Tractors. Also, data for 2-output variables, namely: container throughput (in TEUs) and ship calls were collected.

5.1 Policy Implication and Recommendations

The Implications of the study with respect to the selection of potential container transhipment hub for East Africa are indecisive. I would recommend formation of some kind of alliances between the two ports (i.e. arrangements for coopetition) to attract more demand from containers currently handled as transhipment by the Durban port. Coopetition will not only serve as a strategy to attract more container throughput in the East African region, but also reduce logistics and supply chain management costs that could possibly upsurge from fierce competition between the two on the same potential demand of container traffic.

The dual terminals specialized in container handling (in Dar Es Salaam and Mombasa Ports) are relatively close in terms of proximity within the Global Maritime Logistics and Supply Chain. In this context, they can potentially exploit the advantages/synergies that could be provided by adapting coopetition strategies (i.e. implementing win-win strategy of forming strategic alliance).

The aforementioned argument can be further substantiated by the existing necessary conditions of having an overlapping hinterland for two ports of different countries to opt for coopetition over merely competition strategy. Lessons learned from a similar approach implemented between Malmo and Copenhagen ports (in Sweden and Denmark) has shown positive results; of which in my view could equally work better in serving a share of transhipment cargo destined for Eastern, Central and Southern Africa.

Amongst other requirements, potential shipping lines to be calling along the eastern coast of Africa need a potential hub port exhibit high level efficiency and performance that could serve logistics costs. Comparably, the two East African ports (Dar es Salaam and Mombasa) can be said to exhibit a reasonable level of efficiency given the available resources.

However, it is worth noting that the share of maritime costs in prices of imports entering and export from East Africa is relatively higher, partly due to a lack of direct connections with larger ships serving the major East-West maritime trunk route and markets of North America, Europe and the Far East. Costs of feeder transport and related double handling have contributed higher maritime costs.

All in all, the emphasis should be to put in place a coopetition strategy for attracting potential container demand for the region; of which is currently serving as transhipment by Durban port. Some form of collaboration between container terminals of Dar Es Salaam and Mombasa Ports is expected to work better than fierce competition between the dual terminals of East African ports

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APPENDICES

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Results from DEAP Version 2.1

Instruction file = EG1-INS.TXT
Data file        = eg1-dta.txt

Output orientated DEA

Scale assumption: VRS
Slacks calculated using multi-stage method

EFFICIENCY SUMMARY:

firm  crste      vrste      scale
 1    1.000      1.000      1.000 -
 2    1.000      1.000      1.000 -
mean  1.000      1.000      1.000


Note: crste = technical efficiency from CRS DEA
      vrste = technical efficiency from VRS DEA
      scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

 firm output:          1          2
    1               0.000      0.000
    2               0.000      0.000
 mean               0.000      0.000

 SUMMARY OF INPUT SLACKS:

 firm input: 1     2     3     4     5     6     7     8     9     10
   1       0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
   2       0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
 mean      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

 SUMMARY OF PEERS:
  firm      peers:
    1       1
    2       2

 SUMMARY OF PEER WEIGHTS:(in same order as above)
  firm      peer weights:
    1             1.000
    2             1.000

PEER COUNT SUMMARY:(i.e., no. times each firm is a peer for another)
  firm      peer count:
    1             0
    2             0

SUMMARY OF OUTPUT TARGETS:
 firm output:         1           2
    1           356562.000     319.000
    2           615733.000     468.000

SUMMARY OF INPUT TARGETS:
firm input:  1          2        3      4      5     6      7      8      9     10
    1     725.000 187500.000 3.000 18.000 1.000 9.000 13.000 18.000 8.000 1.000
    2     964.000 312767.000 4.000 12.000 2.000 9.000  7.000 40.000 3.000 72.000
```

FIRM BY FIRM RESULTS:
Results for firm: 1
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	356562.000	0.000	0.000	356562.000
output	2	319.000	0.000	0.000	319.000
input	1	725.000	0.000	0.000	725.000
input	2	187500.000	0.000	0.000	187500.000
input	3	3.000	0.000	0.000	3.000
input	4	18.000	0.000	0.000	18.000
input	5	1.000	0.000	0.000	1.000
input	6	9.000	0.000	0.000	9.000
input	7	13.000	0.000	0.000	13.000
input	8	18.000	0.000	0.000	18.000
input	9	8.000	0.000	0.000	8.000
input	10	31.000	0.000	0.000	31.000

LISTING OF PEERS:

peer	lambda weight
1	1.000

Results for firm: 2
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	615733.000	0.000	0.000	615733.000
output	2	468.000	0.000	0.000	468.000
input	1	964.000	0.000	0.000	964.000
input	2	312767.000	0.000	0.000	312767.000
input	3	4.000	0.000	0.000	4.000
input	4	12.000	0.000	0.000	12.000
input	5	2.000	0.000	0.000	2.000
input	6	9.000	0.000	0.000	9.000
input	7	7.000	0.000	0.000	7.000
input	8	40.000	0.000	0.000	40.000
input	9	3.000	0.000	0.000	3.000
input	10	72.000	0.000	0.000	72.000

LISTING OF PEERS:

peer	lambda weight
2	1.000