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WORLD MARITIME UNIVERSITY

Malmö, Sweden

**A TOTAL FACTOR PRODUCTIVITY ANALYSIS
OF A CONTAINER TERMINAL: DURBAN,
SOUTH AFRICA.**

By

ASANDA ISAAC ZANGWA

South Africa

A dissertation submitted to the World Maritime University in partial
Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

MARITIME AFFAIRS

(PORT MANAGEMENT)

2018

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.

(Signature): 

(Date): *18 September 2018*

Supervised by: Professor. Capt. Daniel Seong-Hyeok MOON (문 성혁)

World Maritime University

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“If you want to go quickly, go alone. If you want to go far, go together.”

Author Unknown

To my family, thank you for the continued moral support and motivation that you gave me during my time away from home.

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ABSTRACT

Title of Dissertation: **A total factor productivity analysis of a container terminal: Durban, South Africa.**

Degree: **Master of Science**

The maritime industry is a vastly growing industry with trends that forces change and adaptation to partakers. The ports no longer play the traditional role of linking the land and sea, but as key nodes in the global maritime chain. Therefore, the emphasis lies on the importance of a proper multi-functional port. Ports encounter challenges such as consolidation, alliances in a container and growing sizes of ships.

The study analyses the performance of Durban Container Terminal, in South Africa through assessment of KPIs (time-related and utilisation) based on secondary data as issued by the port authorities. Furthermore, an evaluation of the technical efficiency of DCT and 10 other African ports is undertaken using input-oriented data envelopment analysis (DEA) and the analysis of slack variable to ascertain possible areas of development.

The results and findings may support the port managers in South Africa to make decisions on whether to increase the capacity of the port. In addition, the port authority may consider the assessment of outcomes in deciding the relative KPIs and reporting.

KEYWORDS: Port Efficiency, Port Performance, DEA, KPIs.

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List of Abbreviations

BOR: Berth Occupancy Rate	41
BTS: Bureau Transport Statistics	29
CRS: Constant Returns to Scale.....	48
DCT: Durban Container Terminal	6
DEA: Data Envelopment Analysis.....	12
DRS: Decreasing Return To Scale	49
GCH: Average Moves per Gross Crane Hour.....	38
GDP: Gross Domestic Product.....	5
IAPH: International Association of Ports and Harbors	9
IRS: Increasing Return To Scale.....	49
KPI: Key Performance Indicator.....	3
MHC: Mobile Harbor Crane	45
NPA: National Ports Authority	1
PMAESA: PORT MANAGEMENT ASSOCIATION OF	9
RMG: Rail Mounted Gantry Crane.....	45
RTG: Rubber Tyred Gantry Crane.....	45
RTS: Return To Scale	49
SA: South Africa.....	23
SADC: Southern African Development Community	4
SWH: Average Moves per ship Working Hour	38
TEU: Twenty-foot Equivalent Unit	4
TNPA: Transnet National Port Authority	1
TPT: Transnet Port Terminals.....	7
UNCTAD: United Nations Conference on Trade and Development.....	29
WMU: World Maritime University	9
VRS: Variable Return To Scale	50
WTO: World Trade Organisation	9

CHAPTER 1: INTRODUCTION

The Ports play a significant role in linking developing countries that have port communities to international trade. The maritime industry is cost driven, if a vessel spends more time waiting outside the port for the next available berth or due to congestion, the cost of transportation of the cargo increases (UNCTAD, 2016). Port managers are continuously trying to achieve high performance and to remain competitive; however, this is possible if there is an existence of a reliable method of the performance measurement.

South Africa is one of the dominant nation's trading by sea. South Africa has eight commercial ports, Durban, Richards Bay Coal Terminal, East London, Port Elizabeth, Mossel Bay, Cape Town, Saldanha, and Coega all managed by Transnet National Port Authority (TNPA) ("Essays," 2013). Transnet is a state-owned enterprise under the Department of Public Enterprises. Transnet has five operating divisions: Freight Rail, National Ports Authority (NPA), Terminal Operations, Engineering and Pipelines, and specialist units related to real estate and project development. (FIT and ITF, 2014).

Figure 1 shows the strategic location of South Africa Ports and their facilities. The port of Durban, Cape Town, Coega specialise in container trade, with transshipment status. Richards Bay Coal Terminal deals mainly with the exportation of dry bulk cargo (coal

from the South African mines in Mpumalanga and Gauteng provinces). However, the Durban port out completes the rest of the ports as it has the characteristics of the main port. Characterised of the main port are cargo volume; throughput, dominance within the hinterland and the variety of the cargo with the diverse shipping line that call the port (Sorgenfrei, 2013; p 77). The Durban port and Richards Bay Coal Terminal together make up 76 per cent of the country’s Sea trade (“Essays,” 2013).



Figure 1: South African ports

Source: <https://www.saoga.org.za/information-hub/port-ha>

1.1 Background

Since the development of containerisation, shipping lines have shifted their focus to the integrated approach to transport providing door-to-door services making them intermodal operators. Containerisation has led to an increase in the size of the vessels as shipping lines benefit more on the economies of scale (Van De Voorde & Winkelmanns, 2002). The merger, acquisition and emerging strategic alliances between shipping lines to maximise transport control places much pressure on ports and increases demand for port efficiency as means of remaining relevant in ever-changing

market conditions (UNCTAD, 2017). Figure 2 shows the current trends in the industry that pose pressure on ports to enhance performance.



Figure 2: Trends in the world container ports

Source: UNCTAD (2017)

The enormous sizes of container vessel are challenging the efficiency of ports and have given rise to competition between container ports regionally and on a global scale (Van De Voorde & Winkelmanns, 2002; Liu, 2010-). Ports provide shipping services to the hinterland and landlocked areas within a particular region; therefore, the performance of a port and competitiveness is critical to regional economies (Mokone, 2016). Insufficiencies within ports are a significant concern to stakeholders and port users. However, with the increased ships size, ports that cannot accommodate larger size ships, experience a considerable decline in volumes of containers as ships reroute to the nearest port with sufficient facilities and delivers efficiency.

A port manager will continuously have challenges of improving, satisfying, and maintaining the required standards. The main categories of key performance indicators (KPIs) that determine the competitiveness and efficiency of a port are financial and

operational indicators. The financial indicators are concerned with costs incurred and the revenue generated by the port through its operations. The operational indicators include container moves, crane moves, container dwell time, truck turnaround time and vessel turnaround time (“port performance indicators”, 1974). A better understanding of elements that constitute to cargo delays in ports and addressing the fundamental causes is essential to improve the effectiveness of the port and the performance (Raballand, Refas, Beuran, & Isik, 2012).

According to Chen et al., (2015), the commonly used port KPIs are: Vessel traffic, the measurement of the number of ships in port at a given period moreover, it is used to determines regional competitiveness; Facility utilisation to measure the usage of terminal facilities and it is essential for berth planning strategies. The study further elaborated on measuring the total number of containers (TEU) handled for the period as the output measurement. The evaluation of the productivity of terminal facilities, particularly quayside cranes used to handle containers summarised as operational efficiency.

The Durban Port is made up of five business units, Durban Container Terminal (DCT), Pier 1 Container Terminal, Multi-Purpose Terminal (City Terminal), Durban Car Terminal (three berths), and Maydon Wharf Terminal (Transnet Port Terminals, 2017). The port has an infrastructure that enables it to service general cargo and containers. Also, adequate road and rail infrastructure provide a direct link with the economic hub of South Africa, Gauteng.

The Durban port is the leading port in the Southern African Development Community (SADC) region and handles the majority of goods imported; therefore, it acts the hub port and gateway to trade in the region. According to Sorgenfrei (2013), a hub port

must have a faster vessel turnaround time, efficient port services, and reliable connection to other modes of transport and strong feeder network, to neighbouring ports, reasonable port charges, and adequate water depth. About 60 per cent of imports and exports pass through the port of Durban; therefore, it takes up a primary role in assisting economic growth in South Africa (“Port of Durban,” 2013). However, recent development indicates that DCT has lost the status (Africa's busiest) to Tanger Med port.

EThekweni Municipality (2017), reported that the Durban port and industries related to the port contribute 20% of the city's GDP. The city of Durban generates 15% of the nation's GDP. Therefore, it of utmost importance for the port sector to be efficiently capitalised and managed in order to be competitive and remain relevant.

According to Essays (2013), the hub ports must have Container-stacking densities of 2000-4000 TEUs per hectare; ship-to-shore gantry crane 50 moves productivity per hour, 3 days' dwell time, truck turnaround time of 30-minutes, the berth should have 15 metres water depth or more and on-dock rail service in order to remain competitive. These significant factors determine the port efficiency and relevance. However, it requires significant capital investments such as infrastructure and expansions.

The Durban port has gone through a series of structural development to accommodate the growth in container trade and port automation. Also, the availability of capital has helped the port to increase the depth of the outer channel to cater to Panamax size ships (Transnet Port Terminals, 2017).

The development of the ports in the region creates threatening competition for the Durban Container Port; therefore, constant evaluation of the port performance and efficiency is essential for the port to remain competitive in regional trade and globally. Such developments include the construction and expansion of the container terminal in Walvis Bay port aimed at accommodating the increasing demand of the port, also to reduce the congestion and aims to be the hub for the SADC (Caschili & Medda, 2012).

Chen et al., (2015), conducted a study on port performance measurement, a comparison between the performance of the two largest ports in the world the Hong Kong port and the Port of Singapore. The findings indicate higher transshipment throughput in Singapore than Hong Kong; this is due to the number of feeder vessels calling in Singapore. Hong Kong port is a gateway port with a transshipment status with a high number of exports from the hinterland; therefore, berth utilisation varies compared to the Port of Singapore. The study concluded that Singapore's terminal productivity is higher than Hong Kong; an assumption of these results was based on the operation of the terminals in Singapore by a single entity (Chen et al., 2015).

If port produces maximum output for a given terminal superstructure then that terminal is efficient (Notteboom, Coeck, & van den Broeck, 2000). It is vital for the Durban container terminal to remain efficient and relevant in order to attract more ships. Stakeholders (investors, policymakers, managers) in all public services such as ports require the performance indicators (UNCTAD, 2016). The early-proposed expansion project to acquire the old Durban Airport site failed due to environmental concern; therefore, TNPA has implemented TWO alternative expansion projects to increase the overall capacity of DCT. The first is the berths widening, lengthening, and deepening at DCT Pier 2. Secondly, the plan to reclaim land between DCT Pier 1 and the naval base in Salisbury Island.

1.2 Research problem

The integration of the Durban port in the global supply chain makes it the vital link of South Africa in the global trade. Thus the efficiency of the port is fundamental. The port handles more 60% of container traffic in the country and it has capacity challenges (Marc Descoins, 2014; EDGE, 2014).

Port authorities are under much pressure to improve port efficiency while remaining competitive due to the growth of globalisation and economies of scale (Almawsheki & Shah, 2015). These call for a need to do studies in the effective handling and management of cargoes to ensure an efficient and seamless flow through the supply chain.

The productivity, production, facility utilisation and customer services characterise the performance of a container terminal. Therefore, quantitative measurement of port performance is imperative in optimising port operations through planning and organising (Chen et al., 2015). Port performance is associated with trade volumes, studies by various authors are in consensus that there is a positive correlation between port efficiency and national trade (Blonigen & Wilson, 2008; Clark, Dollar, & Micco, 2004; Sánchez et al., 2003).

According to TPT (2017), the Durban container terminal has experienced operational inefficiencies such as operational outages. In order to determine how efficient a port is, performance must be measured using relevant indicators such as productivity (Moon, 2018). The analysis of efficiency provides a robust managerial tool for container port planning, benchmarking and it is essential for the survival and competitiveness of the port.

1.3 Aims and objectives

The research aims to provide performance analysis from 2008 to 2017 of DCT. Furthermore, evaluation of operational KPIs as set by the TNPA and TPT to determine the constraints to the performance and to suggest possible solutions to increase the efficiency. Therefore, to achieve aims of the study, a review and analyses of the KPIs of the DCT is required, including the evaluation of performance indicators of the DCT with international standardised indicators. The study will also assess the efficiency and identify constraints to efficiency.

1.4 Research questions

Many stakeholders who use container terminals view optimal port performance differently and use different indicators. The terminal operators monitor and measure port productivity for maximising performance, capital expenditure planning, resource allocation, and capacity planning and profit maximisation. The study, therefore, is aimed at addressing the following questions:

What are the KPIs of the DCT?

What are the factors affecting DCT performance?

How is the performance DCT compared to selected regional and world container ports?

What are the factors hindering the efficiency of the DCT?

1.5 Research Methodology

A mixed method of quantitative and qualitative analysis research methods is used to achieve the purpose of the study. The research has limitations to primary data accessibility due to the nature of the data as the authorities regard to the data as

confidential. Therefore the study relied on secondary data collected from port authorities, Transnet, World Bank, WTO, PMAESA, IAPH and UNCTAD.

The port operator specifies the KPI's as the quantifiable measurements of assessing the progress of the port that must be reasonable and significant (Sorgenfrei, 2013). The measurement of overall productivity depends on some factors such as crane moves per ship working hour, container dwell time, ship turnaround time, quay productivity, terminal area productivity, equipment, and labour input (Talley, 2006). A comprehensive literature review was undertaken using books from WMU library, Google Scholar, academic articles and other platforms to understand what other researchers have studied.

1.6 Significance and Scope of the Research

The study will also assess the overall efficiency of the DCT and benchmark performance of the port. Moreover, the outcome of the study is expected to provide suggestions to optimise the scale of performance and efficiency of DCT and optimum usage of the existing port infrastructure and superstructure.

The study comprises of six chapters. Chapter 1 discusses the background of the study, research problem, the aims and objectives of the study, the research questions and methodology. Chapter 2 provides a comprehensive literature review of port performance and methodologies used to assess port efficiency. Chapter 3 provides an overview of the South African ports, Administration, container sector, constraints to performance and Research Methodology. Chapter 4 focuses on the results analysis and implications, DCT KPIs in comparison with international standardised indicators and operational efficiency. Chapter 5 comprises of conclusion and recommendations. This chapter the conclusion provides the summary of the DCT performance and efficiency.

1.7 Dissertation structure

Figure 3 outlines the structure of the study from chapter 1 through chapter 5.

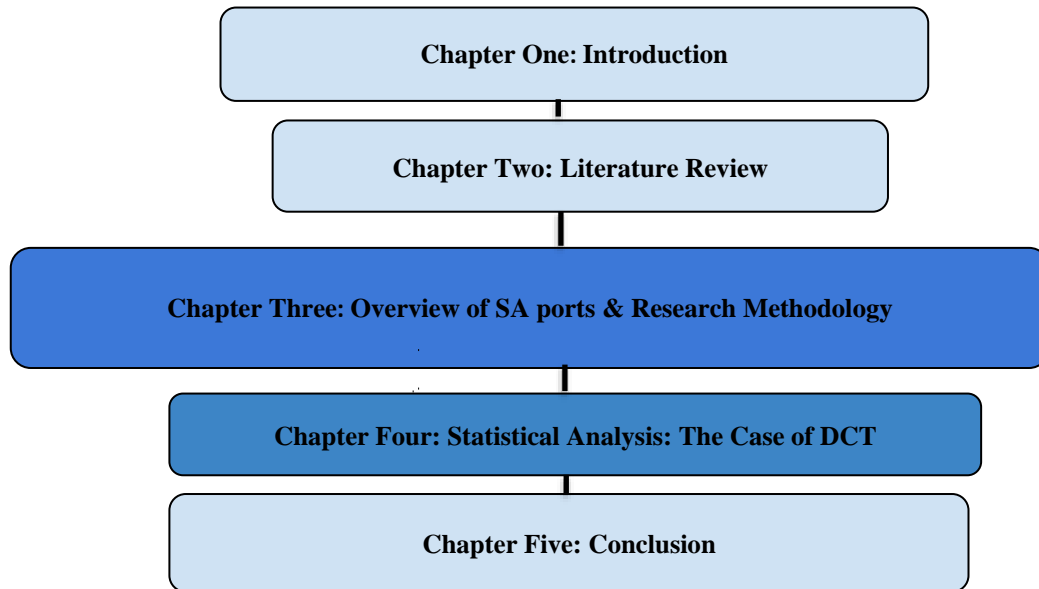


Figure 3: Dissertation structure

CHAPTER 2: LITERATURE REVIEW

The literature review will establish the theoretical framework of the research problem in order to address the research questions and objectives. The literature review will also highlight the port productivity and measures used to evaluate performance. The primary concern of TNPA is operational efficiency within SA's ports maximising the performance levels. The literature will also be used to establish existing measures of port efficiency and the shortcomings of the previous studies. This will help put out a clear overview to the reader of the global perspective.

2.1 Productivity measures

Container terminal processes have become more prominent, and the measurement of their performance is a priority of port managers. The traditional technique utilised to measure the efficiency of a container terminal emphasises on the container moves handled by quayside gantry crane per hour (ICS, 2013). The productivity measures for the study include berth length in meters, service time, waiting time, port time, teu per hectare, vessel characteristics, number of quay cranes, labour productivity, yard cranes and ship productivity, Firstly the broad background on container terminal will be examined and then the specific section which applies to this research proposal and pilot study.

2.2 Port Performance Measures

Port performance is assessed from different perspectives such as effectiveness, relative and technical efficiency and cost efficiency against the optimum throughput (Tulley, 2007). The cost efficiency measures relate to profit maximising for the port. Two other measures of measure productivity, i.e. single and total factor analysis (Moon, 2018).

2.2.1 Single factor analysis

This is the measure of one factor of production by most ports, using a comparison of the percentage of utilisation to optimum throughput. However, Moon (2018) argues that it ignores the substitution and collaboration between the factors of production. Furthermore, indicates the association of high quay productivity with the high number of vessel waiting outside the port, which results in congestion.

2.2.2 Total factor analysis

This uses Data Envelopment Analysis (DEA) and various frontier statistical models that have been developed to give a more precise degree of the technical efficiency of multi-port performance, by using throughput (TEUs) as output and input measures respectively. The frontier analysis can measure technical efficiency simultaneous for each input. Most of the literature uses terminal infrastructure to measure performance.

2.3 Container terminal

The Committee on Productivity of Marine Terminals (1986) defined a container terminal as “a complex facility that involves a variety of different parts and processes, which consists of berth for ships, cranes for transfer of containers between the terminal and the yards for storage of containers, gates for entrance and exit, and several other subdivisions for equipment and administration”,

Figure 4 shows a modern container terminal and the differentiation of the operations, which have an impact on the performance of the port. The berthing area deals with the arrival of the vessel in the port including pilotage, tug assistance depending on the ship's requirements and mooring activities. The apron area is where the handling of the cargo takes place from the terminal to the ship and ship to the terminal. The temporary storage of cargo in the terminal stacking area awaiting further transportation. Connectivity to the hinterland is through road or railway (i.e. gate operations).

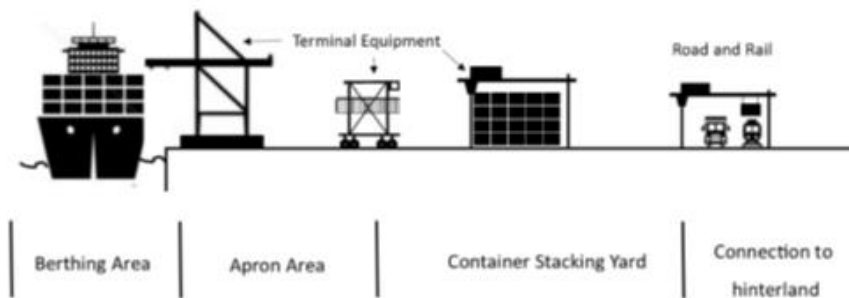


Figure 4: Modern Container terminal (schematic diagram)

Source: Moon, 2018

The evaluation of the port performance assists in taking the corrective decision by port managers on measures to improve performance, benchmarking performance and to meet customer expectations.

2.4 Factors influencing efficiency

Port associated literature has been used to determine efficiency from many perspectives using the established port performance indicators. Port production analyses require several input and outputs. Therefore the evaluation of performance has evolved to a total measure of port performance taking into consideration the

combined inputs such as technology to produce outputs (Suárez-Alemán, Morales Sarriera, Serebrisky, & Trujillo, 2016). The evaluation of port efficiency varies with the input data, geographical location and methodology used (Odeck and Bråthen, 2012).

According to Moon (2018), efficiency is the ratio of output to inputs; however, relative efficiency is the ratio of the sum of the weighted sum of outputs to a weighted sum of inputs. Furthermore, Moon argues that relative efficiency influentials are scale, technical and allocative efficiency.

An extensive review of previous studies associated with port efficiency indicates various methods and different approaches to measure efficiency. Most of the studies have considered the relationship between efficiency and the type of ownership of the port (Tongzon & Heng, 2005; Cullinane & Wang, 2005). The findings suggest that the involvement of private sector improves the technical efficiency of ports; port authorities encourage the private participation in terminals in order to enhance the competitiveness. However, Notteboom et al., (2000) argued that the relationship between port structure and efficiency is not clear.

Wu, Yan & Liu (2010) sampled 77-container terminal around the world using conventional DEA models to assess efficiency. The suggest that out the four selected in inputs (i.e. Capacity of cargo handling Equipment, number of Berths, Terminal area, and Storage Capacity), the number of the berth is the crucial measure of for most container ports. Therefore, they proposed individually investigation of the impact of each input. However, the study emphasizes methodology with incomprehensive empirical analysis of the results.

Yuen, Zhang & Cheung (2013) investigated a way to improve the container port efficiency in China using DEA and Tobit regression model. Their study considered berth number, total berth length, land size, number of quay cranes and yard gantries as inputs and other explanatory variables to determine container throughput (TEU) as the output. Their findings indicated that selected variables inter-port competition has a negative correlation with efficiency growth; however, growth in hinterland GDP has a positive relationship with efficiency.

González & Trujillo (2009) illustrates that there is a relationship between port efficiency (technical efficiency) assessment and the measurement of port productivity, however, changes in efficiency results in an improved level of productivity. Figure 5 shows further clarification on the relationship between productivity and efficiency.

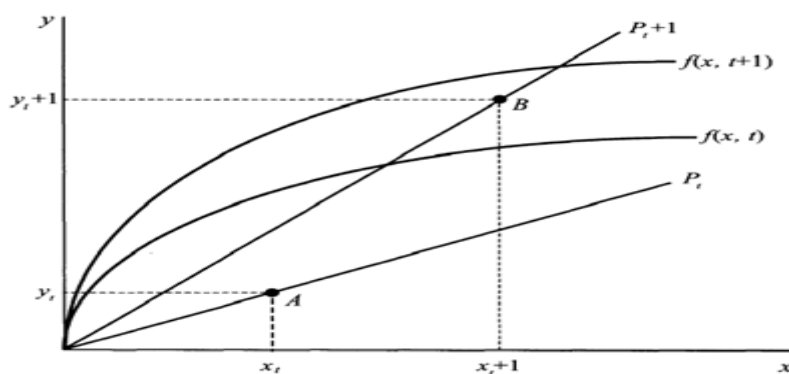


Figure 5: Change in productivity: change in efficiency, scale, and technical change

Source: González & Trujillo, 2009

Figure 5 assumes that a port has acquired new technology (i.e. automated gantry cranes) to improve productivity; however, this will require a considerable amount of efficiency such as training of the personnel to operate the new equipment acquired. In figure 5, x is the production input, and y is the product obtained using x input. P_t indicates the productivity level; frontier is $f(x, t)$. The port's productivity improves from A to B and y increases to y_{t+1} due to the technical changes and the improvement

in technical efficiency is indicated by the distance between productivity and the frontier ($A-f(x,t)$ and $B-f(x,t+1)$) (González & Trujillo, 2009). Therefore, it essential to consider other factors that may influence the productivity that may not be quantitative as demonstrated by González & Trujillo.

Previous studies show that the commonly used approach to port efficiency evaluation is the DEA (Almawsheki & Shah, 2015; Blonigen & Wilson, 2008; Rios & Macada, 2006). Table1 summaries the list of studies on evaluation of the port efficiency of container terminals and ports using various methods and DEA is the most common tool.

Table 1: Studies on evaluation of port efficiency

Author	Method	Input data	Output data	Sample Region
Kutin, T.T.Nguyen & Vallee, 2017	DEA-CCR DEA-BCC	Maximum depth at berth(m), Size of container Yard (m ²), Quay Length (m), Quay Cranes (no), RTG(no), Yard Cranes (no), FTs (no), Trucks (no)	Container Throughput (TEU)	ASEAN Container Ports
Suárez-Alemán, Morales Sarriera, Serebrisky, & Trujillo, 2016	SFA DEA-TFP	Terminal Area(m ²), Berth Length (m), Mobile Cranes (units), Ship-to-shore gantry cranes (units)	Container Throughput (TEU)	70 Developing Countries
Zheng & Park, 2016	DEA-CCR DEA-BCC	Berth Length (m), Yard Area (m ²), Quay Cranes (no), Yard Cranes (no)	Container Traffic (TEU)	Korea & China
Ding, Jo, Wang, & Yeo, 2015	DEA, MPI, Tobit regression	Terminal Length (m), Handling Equipment quantity, Staff quantity	Container throughput (TEU)	Chinese Ports
Almawshaki & Shah, 2015	DEA-CCR	Terminal Area(ha), Quay Length (m), Quay Cranes (no), Yard Equipment (no), Maximum Draft (m)	Throughput (TEU)	19 Middle Eastern region ports
Figueiredo De Oliveira & Cariou, 2015	Regression DEA	Port Area(m ²), Storage Area (m ²), Length of berth(m), Quay Cranes (no), Yard Cranes	Container Traffic (TEU)	200 container ports (global)
Yuen, Zhang, & Cheung, 2013	DEA	Number of berth, Land size, Total Length of berth(m), Quay Cranes (no), Yard Gantry Cranes	Container Throughput (TEU)	Chinese Ports
Wu, Yan, & Liu, 2010	DEA-CCR	The capacity of cargo handling Equipment (no), Berths (no), Terminal Area(m ²), Storage Capacity(TEU)	Container Throughput (TEU)	77 Global Container Ports

Source: Author

The input data used in many of the studies include the berth length or berth number, quay cranes and yard equipment as the significant inputs used to assess the efficiency. Zheng and Park (2016) used DEA-CCR and DEA-BCC to gauge the efficiency of container terminals in Korea and China, and they support the use of only one variable between the number of berth and berth length. Furthermore, they argued that using both berth length and number of berth reduces the accuracy of the results. The study also argues that some of the studies use total facilities and equipment for each terminal that was far different from the actual status of the facilities and equipment that exists in the port studied, therefore, emphasising on the use of credible data source.

Ding, Jo, Wang, and Yeo (2015) employed various methods (i.e. DEA, MPI, and Tobit regression) in their study to evaluate the relative efficiency of small and medium-sized container ports in China. The Tobit regression was applied to quantify the explanatory variables (i.e. workforce structure, state-owned shipping line shareholding, number of terminal operators, registered capital and shipping routes) that affect terminal productivity efficiency. The results of the study found that among the chosen explanatory variable, the number of terminal operators has an adverse effect on the efficiency. The study shows that attracting shipping lines to invest in terminal operations improves efficiency.

The productivity is the ratio of outputs over inputs often used to benchmark performance of a port by examining how well the inputs are used to produce its outputs. Productivity changes correlate with the changes in efficiency level. A Total Factor Productivity methodology has been developed and used due to the various number of inputs and outputs (Suárez-Alemán et al., 2016). A number of Scholars chose port productivity as the prime indicator that reflects port efficiency (Suárez-Alemán et al., 2016; Moon and Woo, 2015; Ding et al., 2015).

The literature review provides a background of the methodology utilised to evaluate the level of productivity and efficiency. The literature dealt with the variables related to port performance evaluation by various authors as well as the broad background of the container terminal. It also serves as the bases for the data-consideration for similar studies. A general overview of the South African container port system, port administration and the research methodology with research design and sampling of the study is discussed in the next chapter.

CHAPTER 3: SOUTH AFRICAN PORTS AND RESEARCH METHODOLOGY

Ports are continually changing their design and infrastructure to cope with the growing sizes of the ships and customer needs. There have been radical developments in cargo handling technology, and labour requirements, therefore, it is essential to understand the general pattern of the developments and applied solutions by port managers (Alderton, 1999). The previous chapter discussed literature review with the variables related to port performance evaluation by various authors as well as the broad background of the container terminal. This chapter provides an overview of the South African Container port system, port administration, factors limiting performance and the methodology.

In 2016 the South African government elaborated on the importance of maritime industry, the recognition was through the national budget speech and South African Maritime Road Map and Operation Phakisa a 2030 vision to make SA a recognised maritime nation. Furthermore, SA location in the oldest maritime trade route provides an advantage of being an ideal halfway station for international trade and linkage between West and East.

3.1 South African Container Port System

The South African ports serve as a gateway to trade between South Africa (SA) and Southern African region trade partners and act as the hub for traffic to and from the rest of the world. Approximately 98% of SA's exports are conveyed via the sea through the eight commercial ports (SAMSA, 2013). The level of maritime connectivity of SA is high compared to other Sub-Saharan Africa, a status to some extent justified by its advanced level to generate and attract freight. South African ports assume a fundamental part in satisfying the nation's social and monetary advancement targets. Figure 6 maps out the location of the South African ports and their connectivity to the country.

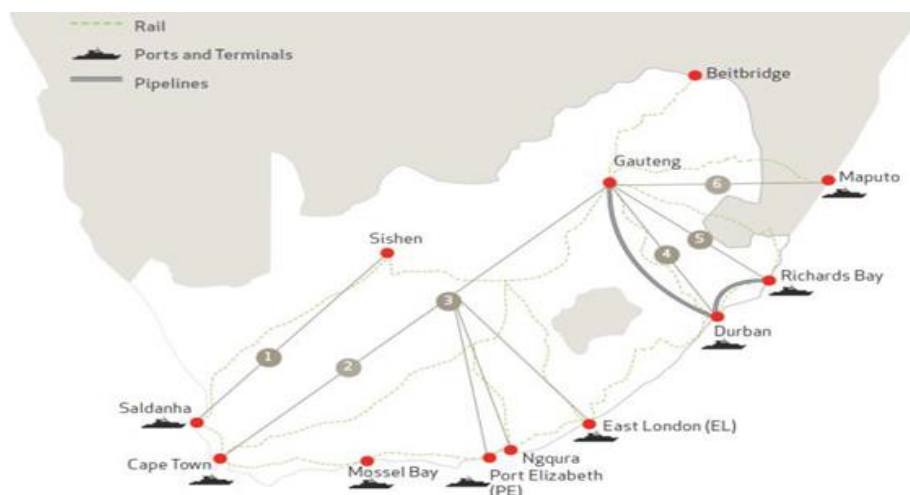


Figure 6: South African ports

Source: SAMSA (2013)

The location of SA gives rise to prospects of becoming the leading transshipment hub in the continent with the most robust linkage to the Asia and the American continent. Cargoes destined for neighbouring countries within Africa are transported via the Durban port.

The eight commercial ports are (i) Specialised bulk port (Richards Bay Coal Terminal, Saldanha Bay and Mossel Bay), (ii) multipurpose ports (East London, Port Elizabeth Durban, and Cape Town) and (iii) transshipment terminal Ngqura. These ports are complementary not competing with each other. Table 2 shows the types of the ports with the maximum draft, with Durban, Cape Town, East London, and Port Elizabeth as multipurpose ports. The port of Ngqura with deep water specially constructed to handle transshipment cargoes and integrate global market within the Sub-Saharan Africa region thereby acting as a hub port. Richards Bay, Saldanha Bay, and Mossel Bay ports have a deep-water draft to handle the specialised bulk ships.

Table 2: South African Port's terminal and facilities

Port	Terminal (no)	Berth (no)	Draft (m)	Sector
Durban	9	58	12.8	Containers, cars, Break Bulk, Liquid Bulk
Cape Town	7	34	15.9	Containers, Break Bulk
Ngqura	4	4	10.4	Containers
East London	4	12	14	Cars, Break Bulk
Port Elizabeth	5	12	14.5	Cars, Containers, Break Bulk
Saldanha Bay	3	6	23.2	Bulk, Break Bulk
Mossel Bay	2	8	7.5	Liquid Bulk, Fishing
Richards Bay	6	23	22	Bulk and Break Bulk

Source: TNPA (2018)

Figure 7 illustrates the performance changes in all commodities between 2016 and 2017 graphically. The containers are expressed in million TEUs, bulk and break bulk millions tons and vehicles expressed in units. There was a slight improvement in the vehicles handled in 2017. However, the overall performance declined.



Figure 7:2016/17 performance (Commodities)

Source: TNPA

According to TPT (2017), report for overall ports indicates that Container volumes were below budget for 2017 due to the global economic slowdown 4 395 962 TEUs (2016: 4 366 376 TEUs). The report shows the declining commodity prices and low international demand for bulk and break bulk minerals lead to a negative impact in the bulk export commodities 4.7% and 21% for break-bulk lower than 2016. Automotive volumes declined by 4.2% in 2017 to 679 792 (2016: 709 891).

3.2 Port Administration

Transnet National Port Authority (TNPA) under the National Ports Act 2005 manages and regulates South African ports and act as a service provider for port services. Private sector participation is limited to subsector and vessel repairs under lease agreements (SAMSA, 2013). Transnet is a state-owned enterprise under the Department of Public Enterprises with five divisions, Freight Rail, National Ports

Authority (NPA), Terminal Operations, Engineering and Pipelines, and specialist units related to real estate and project development (TNPA, 2018).

TNPA operates as the property owner; therefore, private entities lease port assets for the provision of maritime ancillary services. Another division of Transnet Limited, Transnet Port Terminals (TPT), enjoys a monopoly in the handling of cars and dominates the handling of containers and break-bulk cargoes. TNPA is predominantly an asset manager, providing a limited range of port including marine services (pilotage and towage) while TPT handles cargo operations notable in container trade.

3.3 The Durban Container Terminal (DCT)

According to TPT, the Durban container terminal is Africa’s busiest terminal ranked among the top in the world. There four container terminals operating as multiple gateway systems, Cape Town, Port Elizabeth, Ngqura (transshipment) with Durban operating as the main port. The overall container capacity of these ports is 7.7 million TEUs, 65 per cent handled by the Durban container terminal (TPT, 2018). The Durban container terminal operates as two combined terminals (Pier 1 and 2). Table 3 shows the facilities of both Pier 1 and Pier 2 container terminals. The total container capacity of the terminal is 3.6 million TEUs and eight berths.

Table 3: DCT facilities

Facilities	Pier 1	Pier 2
Capacity	0.7 TEU	2.9 TEU
Berths	2	6
Draft	12.5m	12.2m

Source: http://www.transnet-tpt.net/Ports/Pages/Durban_Container.aspx

According to Transnet (2017) DCT operations, encounter challenges, especially when compared with international performance benchmarks. The main factors behind lower performance levels are ship call patterns, ship size, tidal effects and the container terminal facilities. This is associated with limited storage space available per hectares and lengthy internal moves between the quay and staking yard. DCT operate as two terminals pier 1 and pier 2 with a theoretical capacity of 3.4 million TEUs. Port of Durban handles almost 65% of SA's shipping and provides strong hinterland connection to Johannesburg and neighbouring countries. Figure 8 shows the current layout of Durban port with an indication of different facilities and intermodal links (road and railway).

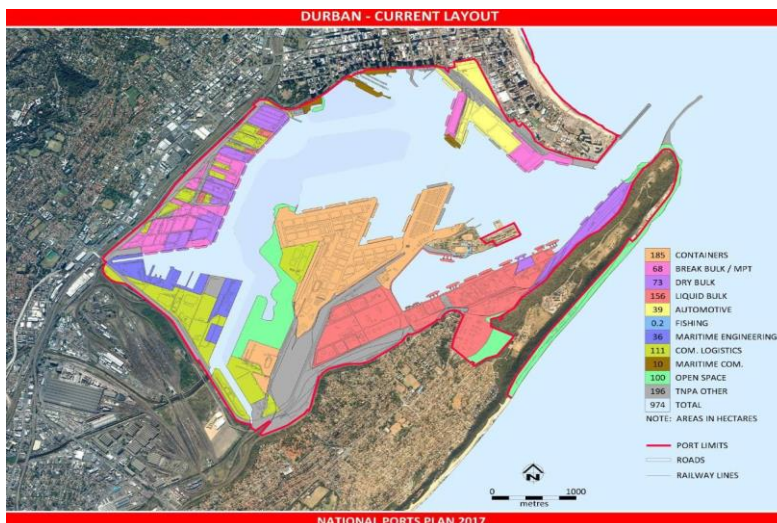


Figure 8: Durban Port Layout

Source: TNPA (2017)

3.4 Performance Limiting constraints of Container Terminals

The container terminal capacity is the maximum number of TEU moves that the terminal can achieve per annum (TEU moves/year). According to Moon (2018), to determine the maximum capacity of a container terminal the main factors to consider.

(i) The Berth Capacity which is the number of TEU moves/year that the berths can

physically handle and (ii) The Container Stacking Yard Capacity which is the number of TEU moves/year that the container stacking yard generates and other constraints which affect the capacity such as container crane capacity, rail terminal capacity and road terminal capacity. Figure 3 shows the factors to consider when evaluating the performance of the container terminal. The terminal activities are broken down into three components (i) Berth, (ii) Yard and (iii) Gate operation.

3.4.1 Berth Capacity

This section shows the calculation of the throughput or capacity that a berth of a container terminal could physically handle. Factors like cranes available and crane moves per ship influence the berth throughput. Figure 9 indicates the importance of synergy in the port activities in order to deliver superior services. The pipeline irony demonstrates the port's activities and how to possibly identify areas that are slowdown performance.

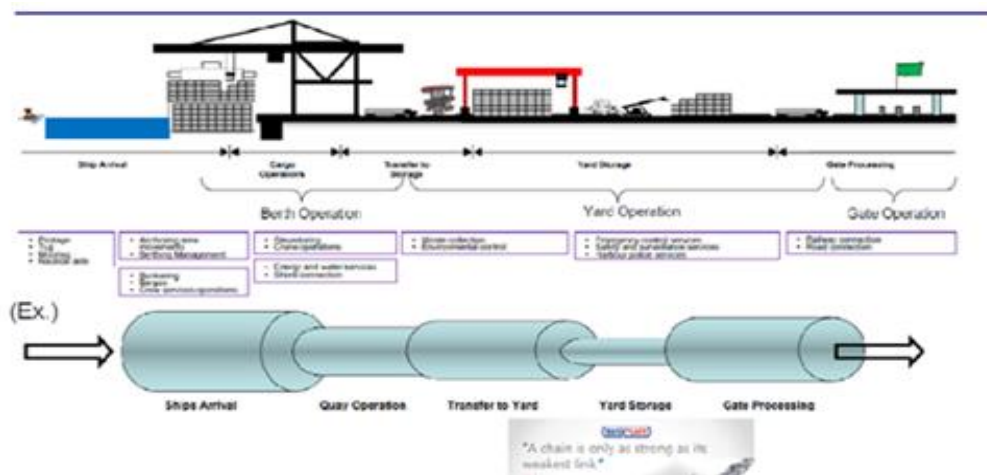


Figure 9: Schematic Diagram Container Terminal Operation

Source: Moon (2018)

3.4.2 Yard Capacity

The maximum number of container moves that the stacking yard can achieve per year. This should equal the berth capacity for a container terminal to be operating at optimal efficiency (Moon, 2018).

The number of TEUs handled per square meter of storage area in a given period. It also considers the equipment productivity measure (the number of container moves made per working hour).

3.4.3 Gate operation

Three common entities are passing through port gates, which include a driver, a truck, and a container. The number of containers passing through the gates has increased dramatically due to the increased size of the vessels. Therefore, it is essential that the gate operation be set to reduce the truck turnaround time.

3.5 Research methodology

Port productivity of the Durban container terminal is described by suboptimal and inconsistent performance due to the equipment failure and weather conditions. Insufficiencies within ports are a significant concern to stakeholders and port users. The aim of this study is to test the use of the current port infrastructure and resources to ascertain and improved levels of productivity, reliability, efficiency. Here the research methodology is explained with the rationale behind the sample selection and the criteria used, to describe the instruments and methods used to collect data and to elaborate on the analysis design of the collected data.

3.5.1 Research Design

The research methodology will be based combined method of quantitative and qualitative analysis in order to acquire ample data to assist in analysing the performance. The quantitative method will be a focus on the data of the current infrastructure and resources at the DCT, in line with the related variables by the KPIs for measuring productivity. The quantitative data relating the port productivity such as ship productivity, crane productivity, quay productivity, and time-related KPIs is collected. This study, therefore, seeks to respond to ‘what’ and ‘how’ questions; therefore, mixed methods of research was used to develop the results and provide a complete picture of the research.

3.5.2 Data collection procedures

The study-collected data from the publicly available sources such as terminal operator’s websites (TPT), TNPA audited reports, International Association of Harbours and Ports (IAHP) and Containerization International Yearbook, including statistics for containers handled as well as conventional berths and reports published by the port authority. These reports contain sufficient information about the organisation’s annual performance, strategies, achievements and targets. Therefore, the researcher makes use of the reports available from 2008 to 2017.

3.6 Input and Output Variables

The productivity of ports and terminals depends on the efficient use of land, labour and capital (Dowd and Leschine, 1990). However, the port authorities decide on performance indicators. The SA’s ports regulator assess and approve the KPIs and their weighting on a per port basis as suggested by the TNPA and TPT. This justifies the gaps in the data collected on KPIs collected from the reports published by TPT and TNPA as it appears that they are subject to change based on evaluation by the Ports Regulator of SA.

3.6.1 Output Variable

Most of the studies as shown in the literature uses total tonnage throughput or container throughput to assess the port performance. Roll & Hayuth (1993) in their port performance comparison study used service level as the output variable. Annual container throughput is the dependent variable of the study. The Bureau of Transportation Statistics (BTS) (1992) defines the container throughput, as “A measure of the number of containers handled over a period.” The literature as discussed in the previous chapter shows that the standard measure of productivity of a port is the container throughput measure in TEU. Therefore, the dependent variable of the study is the container throughput.

3.6.2 Input Variables

The independent variables for the study will be grouped in time-related KPIs and ship related KPIs. The study emphasises on operational KPIs, as they encompass a wide range of measurable factors from the time the vessel arrives in the port until the last line let go (vessels sails). The selected input variables for evaluation of performance were terminal storage capacity (TEUs), the number of quay cranes, quay length (m), yard equipment (units) and maximum draft (m).

3.7 Sample Size

Almawsheki & Shah (2015) argues that for an appropriate port efficiency benchmarking, the DMUs selected must be similar. Therefore, this study focuses on container terminals in the African region as ranked by UNCTAD and other databases. However, the lack of complete and reliable data some ports were excluded from the sample. The sample size includes 11 African ports as shown in Table 4, which narrows

down the scope for comparison of the results, and the summary of the DMUs is provided in chapter five.

Table 4: Sampling DMUs

Country	Port
South Africa	Durban Container Terminal
Kenya	Mombasa
Djibouti	Port of Djibouti
Nigeria	Apapa
Morocco	Tanger Med Port
Tanzania	Dar Es Salaam
Ghana	Tema
Cameroon	Doula
Togo	Lome
Côte d'Ivoire	Abidjan
Egypt	Port Said

Source: Author

3.8 Data analysis and validity procedures

The methodology will address the research questions by covering the content necessary and draw a meaningful conclusion on port productivity capabilities and efficiency in the DCT. The researcher analysed the data collected using Microsoft Excel (2016) and extracted statistical graphical illustrations and discussed in the next chapter. The study utilises DEA to assess efficiency and results presented in the form of tables and figures then discussed thoroughly in Chapter 5. The DEA recognises the smallest set enveloping the input-output observations for all DMUs and attempts to detect a production unit in comparison with others (Kutin at al., 2017).

This chapter discusses South African container port system, port administration and the factors limiting performance and the role of Transnet in relation to ports and terminals. The research method chosen for the purpose is utilised in the next chapter for assessing port performance and efficiency scores in comparison with other ports.

CHAPTER 4: STATISTICAL ANALYSIS: THE CASE OF DURBAN CONTAINER TERMINAL

The rationale behind the methodology of the study has been discussed briefly with the data collection tools, the variables, and the sample with sampling method. In this chapter, the results will be discussed and elaborated in order to derive their meaning.

4.1 Data

The data collected from various sources such as port websites, reports and other sources with the concern for reliability and availability has been analysed using various tools. Figure 10 shows the primary data a port should collect in order to evaluate its performance levels. However, the port authorities classify the data collected as confidential as it is used to assess their productivity levels through benchmarking with competitors. The information collected by the port is used for the statistical purpose, performance measurement in order to have a record of accomplishment for benchmarking current performance with previous results; this is useful in determining the areas of improvement and development.

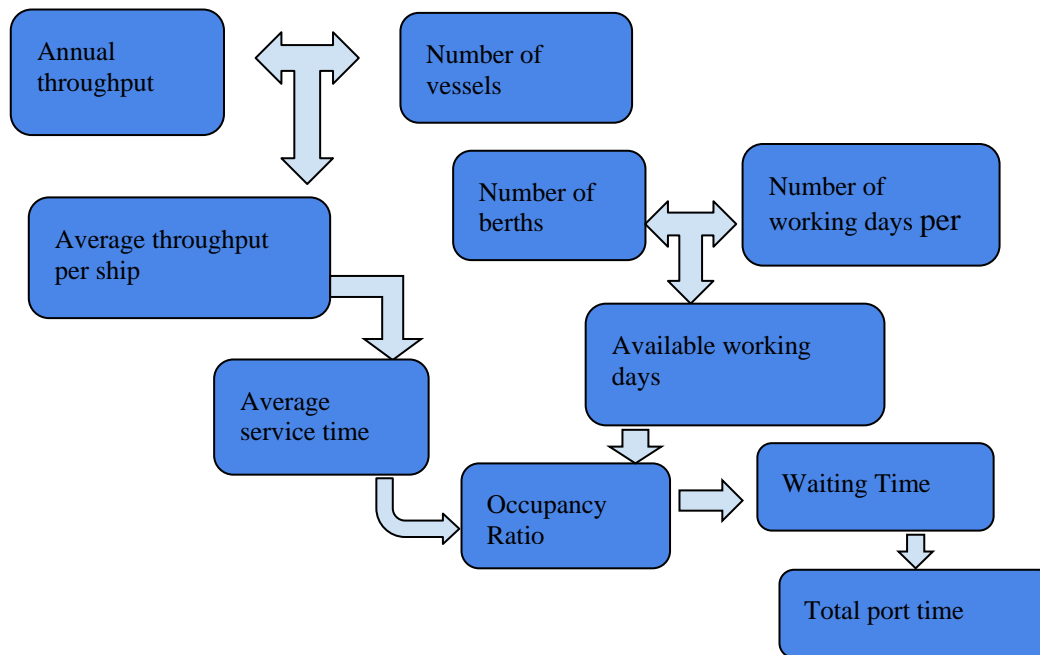


Figure 10: Basic data a port should collect

Source: Alderton (1999; p215)

The annual throughput is the records of the total cargo or containers handled by the port on a yearly basis; this is useful in determining if there is a need for increasing capacity in the yard or the port. The number of the vessel is often used to track the traffic in a particular port. However, for containers, there is no correlation between vessel traffic and throughput. The average service time, waiting time and total port time are related to quality measures, a higher waiting, average service time, leads to greater port time and that is regarded as poor service quality as vessels prefer to berth on arrival and reduce total port time.

4.2 Durban Container Terminal Annual Throughput

The Durban container throughput was collected from the TPT website. Table 5 shows the combined throughput for pier 1 and pier 2. The lowest throughput achieved was in 2009, due to the economic circumstances, however, was able to reach 2.7 million TEUs in 2011 and 2015.

Table 5: Durban container throughput

Year	Throughput (TEUs)	Year	Throughput (TEUs)
2008	2 642 558	2013	2 632 515
2009	2 384 879	2014	2 664 330
2010	2 529 209	2015	2 770 335
2011	2 720 915	2016	2 620 026
2012	2 568 124	2017	2 699 978

Source: TPT

As seen in table 5 the throughput has increased over the past 10 years. Figure 11 graphically illustrate the trend of the throughput changes for the past 10 years. UNCTAD (2017) has predicted a 2.8% increase in global trade by between 2017 and 2022 due to the fast growth in container trade and dry bulk commodities.

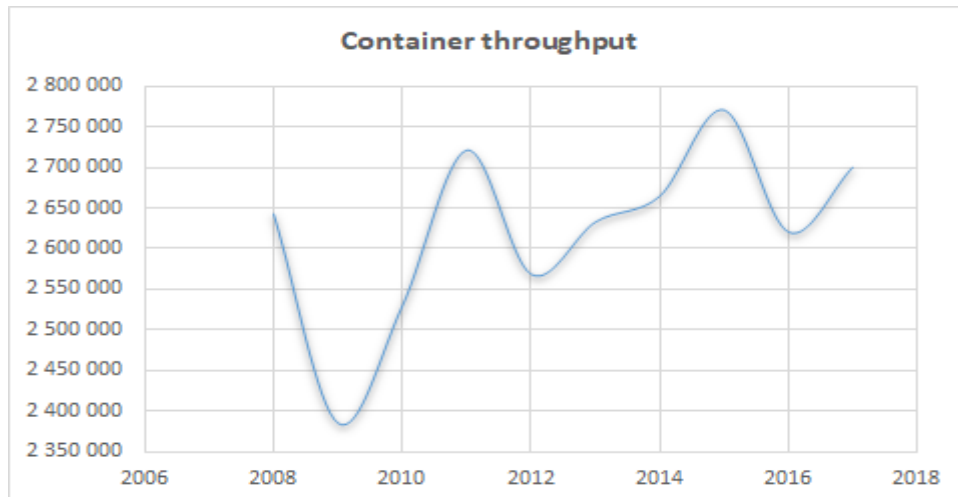


Figure 11: DCT Container Throughput

Source: TPT

Figure 11 shows the graphical trend of the DCT throughput from 2008 to 2017. In 2009, there was a 10% decline in the through due to the economic downturn (global economic crises). However, after the market recovery container volumes increased by 6% in 2010 followed by a decline in 2011. In 2012 and 2015 the throughput declined by 5% due to unfavourable ship turnaround time, equipment breakdown and equipment age as well as the implementation of a new operating system (Navis) (Transnet report, 2012; 2015).

Transnet predicts that the container throughput for DCT will increase and therefore, national ports plan has set out to increase the current capacity of the port to 3.9 million TEUs in 2023 through deepening and widening of the berths, furthermore in 2028 the total capacity is expected to be 5.2 million after the construction of the Salisbury Island infill project.

4.3 Vessel Traffic

Due to data accessibility and availability, the vessel traffic and gross tonnage were obtained for the past four years (2014 to 2017). Figure 12 indicates the monthly vessel traffic calling DCT. According to the results, the number of container vessel calls shows a steady decline from January to December in the period shown. The year 2014 shows the highest total number of container vessel serviced followed by a decline of 7% in 2015, which later doubled as 2016 resulted in a 14% decline in traffic. The numbers continued to decline as 2017 resulted in a 15% drop. According to TPT (2017) the global economic challenges, lower draft and terminal operational outages affect the shipping lines to bring more transshipment cargoes. It is possible that the vessels have opted to reroute during this period due to the high port cost and the port developments and upgrading of port facilities have an adverse effect on the vessel calls.

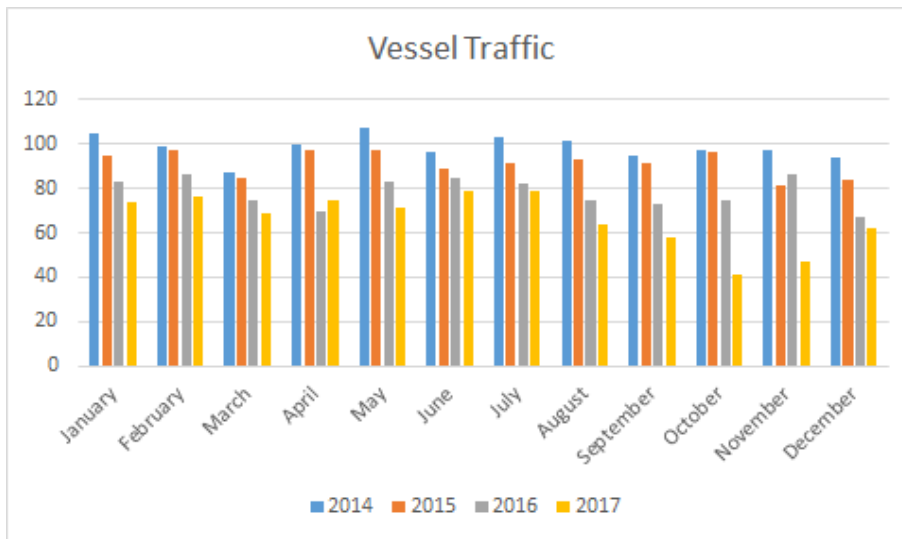


Figure 12: DCT vessel traffic (2014-2017)

Source: TNPA

4.4 Operational Efficiency and Productivity

TPT and TNPA are geared to improving the operational efficiency of the ports in SA. It is necessary to enhance port efficiency and reduce the container dwell time to improve trade competitiveness and cost reduction (UNCTAD, 2017). The primary measures of operational efficiency of terminals are (i) Average time at anchor, (ii) Ship turnaround time, (iii) moves per ship working crane (SWH), (iv) moves per gross crane hour (GCH), (v) container dwell time, (vi) berth occupancy or utilisation rate.

4.4.1 Average Time at Anchorage

This is the time a vessel spends waiting to berth; this is due to, adverse weather conditions, vessels arriving ahead of the scheduled berthing time, handling equipment failure, berth outages due to construction activities at high productivity berths, Industrial action by labour (Transnet, 2013). However, inefficient port operations may also cause a higher anchorage time. Port managers are able to deduce the time a vessel spend waiting to berth as a Waiting Ratio (waiting time/service time).

Figure 13 shows the average anchorage time of the vessel calling the Durban port from 2014 to 2017; the data does not indicate which vessels are affected the most. Therefore, it not possible to determine the waiting time for container vessels and the arrival pattern.

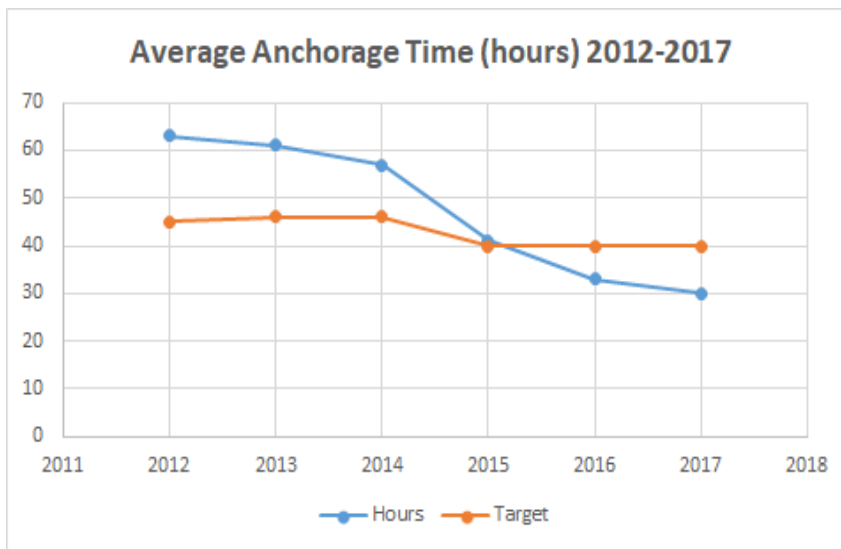


Figure 13: Average Anchorage Time

Source: Transnet Reports

In 2012 to 2014, the average time spent at anchorage is above the ports target and therefore vessels have to wait longer to be serviced, an indication of poor performance by the port. However, in 2015 to 2017 delays have been reduced to below the targets of 40 hours, hence improved service level for customers. Furthermore, Transnet plans to reduce the shift changes time allocation to minimise the waiting time. The delays are caused by an equipment breakdown, administrative duties and yard cargo flow with improper stacking.

4.4.2 Average Moves per Ship Working Hour (SWH)

SWH is the measurement of crane efficiency. As shown in figure 14 the SWH from the data obtained indicates both pier 1 and pier 2 performance is lower than the target moves. Pier 1 performed higher than the targeted moves in 2015 and 2016 and however declined in 2017. Pier 2 is underperforming, as it has not reached the target set. The decline in performance is due to the equipment failure as reported by Transnet, leading to high port time and anchorage time as vessels waiting for berth availability. According to Ports Regulator of South African (2015), DCT has the highest crane efficiency in Southern Africa featured in top 100 international rankings. Crane efficiency can be improved with proper training of the operators and improvement on crane intensity.

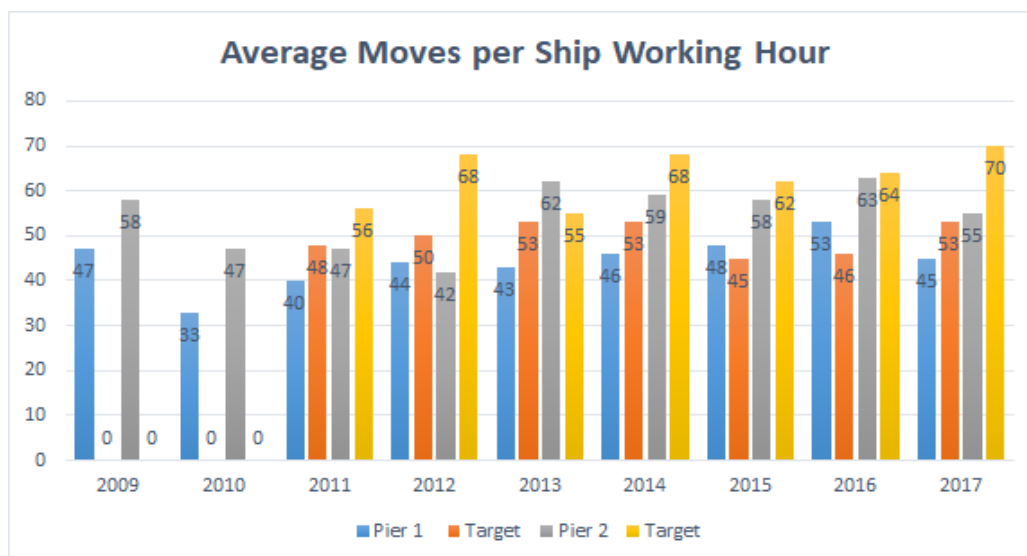


Figure 14: Average Moves per ship Working Hour (SWH)

Source: Transnet reports

4.4.3 Average Moves Per Gross Crane Hour (GCH)

GCH represents the number of containers each crane moves, and it is the standard measurement of productivity in container handling (Ports Regulator, 2015, p18).

Figure 15 illustrates the average GCH that DCT achieved from 2008 to 2017.

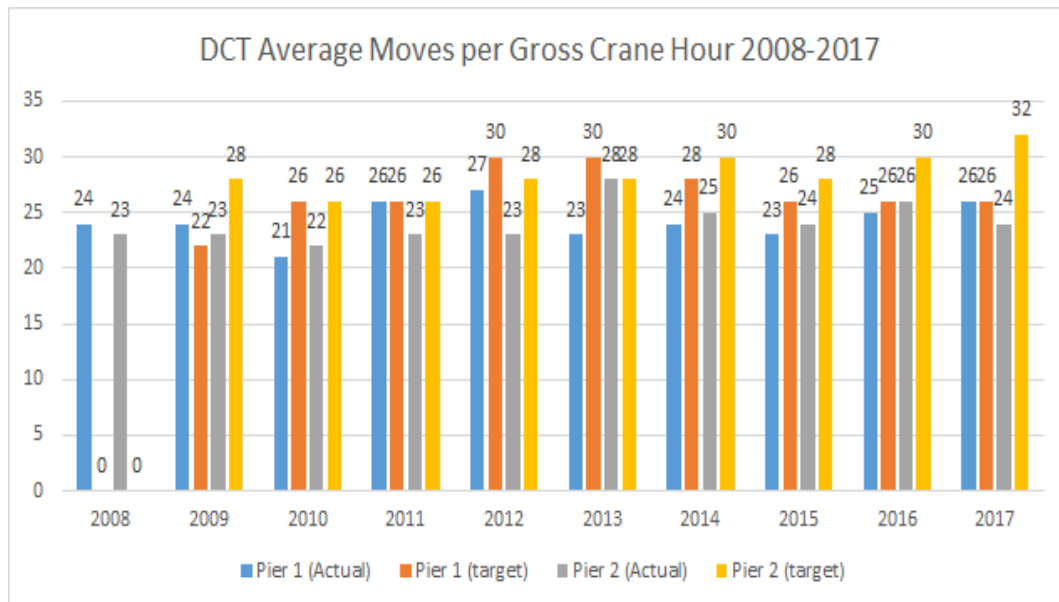


Figure 15: DCT Average GCH 2008-2017

Source: Transnet report

GCH for the terminal has varied from 2008 to 2014 as noted in figure 15. The graph indicates that both pier 1 and 2 have performed below the target; this could be because the setting of the targets using previous performance rather than a derived standard. The authority’s strategic framework target for 2019 is to achieve 35 moves per hour; however, with 26 GCH for pier 1 and 24 pier 2 seems far below than desired moves in the next year. According to UNCTAD (2017), average crane productivity in Asia is typically 35 to 40 moves per crane per hour and in Western Africa 20 moves. DCT average cranes moves of 23 to 30 moves are far higher than Western Africa but lower than Asian Terminals, hence the need for improvement in order to remain competitive. There is a possibility to achieve 30 or more gross moves with the efficient use of the tandem lift cranes at the port.

4.4.4 Ship turnaround time

This indicates the total time the vessel spends in port from arrival until the departure (ICS, 2013, p42). Generally, a ship is not making money while in port but paying for port services and shipping lines prefer to keep the turnaround time to 24 hours. South African ports have the most expensive port tariffs, and therefore it is crucial that ships be serviced much efficiency to minimise the port stay. Figure 16 illustrates the average turnaround time of DCT (2008-2017).

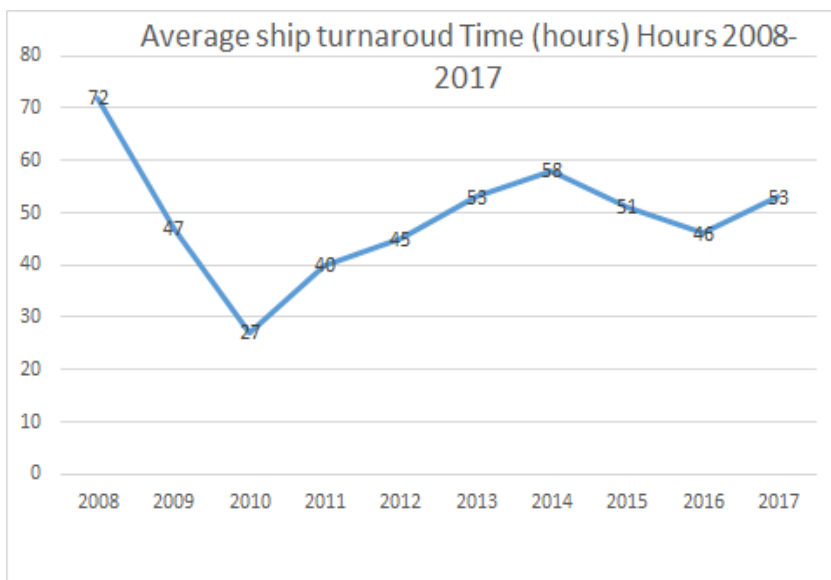


Figure 16: Average Ship Turnaround Time

Source: Transnet reports

The terminal has recorded the highest Average Turnaround Time in 2008 of 72 hours with a steady decline throughout the 10-year period. This could occur due to a number of factors such as GCH, SWH, equipment failure and other factors, which may increase the time of the vessel in port. Hence, Transnet focuses on operational improvements by maximising deployment of cranes for vessels, minimise downtime, reduce shift change delays and improve operator and technical skills. According to UNCTAD, the average turnaround time is 1.37days or 33hours worldwide; however, containerships

prefer to be in the port limits for less than 24 hours. The results indicate that DCT has a more significant turnaround time than the desired by the shipping lines an indication of an area for improvement.

4.4.5 Berth Occupancy Rate (BOR)

The port managers want to achieve the highest utilisation rate of the port facilities. However, this requires suitable methods such as resource planning and coordination. The BOR indicates the total occupation time of the berthing facilities. BOR is calculated as the total time of vessel at berth divided by the total berth hours available. A high BOR is highly associated with a very high rate of utilisation of port facilities and leads to a proportion of congestion in the port (Moon, 2018). Table 6 shows Durban port’s average BOR from 2014 to 2017.

Table 6: Average Berth Occupancy rate

Average Berth Occupancy Rate (%)		
Year	Rate %	Target %
2014	78	85
2015	70	70-80
2016	69	70-80
2017	61	65-75

Source: Transnet IR report 2016/17

The Durban port has 58 berths with a length ranging from 148m to 350m and the 12.8m draft. In 2014, the BOR was 78% with a steady decline to 2017. According to the industry norm, the BOR of a port with six or more berths the BOR ranges from 60% to 75%. The target set for 2014 to 2016 are above the industry standard which if

achieved the port would be congested. Table 7 illustrate the recommended BOR for European ports. Unreliability regarding the reporting should reflect separate sectors of the ports.

Table 7: Average BOR in major European ports

Berths (no)	Low	Average	High
1	25	35	45
2	40	45	50
3	45	50	55
4	55	60	65
5	60	65	70
6 or more	65	70	75

Source: Dragovic (2005) as cited by Moon (2018)

In comparison with the average BOR of the European ports and Durban port, the actual BOR has been within the suggested range. However, BOR varies from port to port. Furthermore, UNCTAD, as cited by Moon (2018), has similar recommendations on berth utilisation measure of a port with 6 or more berths as shown in figure 17.

Number of berths	Optimum utilisation	Container terminals		General cargo berths	
		Tw / Ts	Tw / Ts	Tw / Ts	Tw / Ts
		K = 4	K = ∞	K = 1	K = 2
1	0.40	0.42	0.33	0.67	0.50
2	0.50	0.22	0.18	0.33	0.26
3	0.55	0.14	0.12	0.22	0.17
4	0.60	0.12	0.10	0.18	0.14
5	0.65	0.12	0.10	0.17	0.13
6 or more	0.70	0.12	0.10	0.19	0.14

Note: average waiting-time to service-time ratios shown for '6 or more' are for 6 only.
Source: UNCTAD, 1986 and Hans Agerschou (2004), "Planning and design of ports and marine terminals", 2nd edition, Thomas Telford.

Figure 17: Optimum Berth Utilisation

Source: UNCTAD (1986), cited by Moon (2018)

4.4.6 Average Dwell Time

The amount of time the container spends in ports is determined by the status of the container (import, export and transshipment) and efficiency of communication between the participants involved. Customs clearing procedures also affect on the dwell time. Ideally, the maximum time (days) allowed from the container in DCT (Pier 1 and 2) is three days for import, five days for export and ten days for transshipment containers to accommodate the connections and reshuffling of the containers. However, that is not always the case; Table 8 shows the various scenarios where the average dwell time for exports exceeds the allocated number of days.

Table 8: Average Dwell time

Average Dwell Time (days)						
Terminal	Days	2014	2015	2016	2017	Target
Pier 1	Import	3	3	3	3	≤3
	Export	5	6	5	5	≤5
	Transshipment	6	9	6	6	≤10
Pier 2	Import	2	2	2	3	≤3
	Export	6	7	5	6	≤5
	Transshipment	8	9	6	6	≤10

Source: Transnet Port Terminals

Cargo dwell time is a complementary measure to port time and berth productivity, as it measures the efficiency in cargo stay in port. Figure 18 indicates the average cargo dwell time of sub-Saharan Africa in 2011.

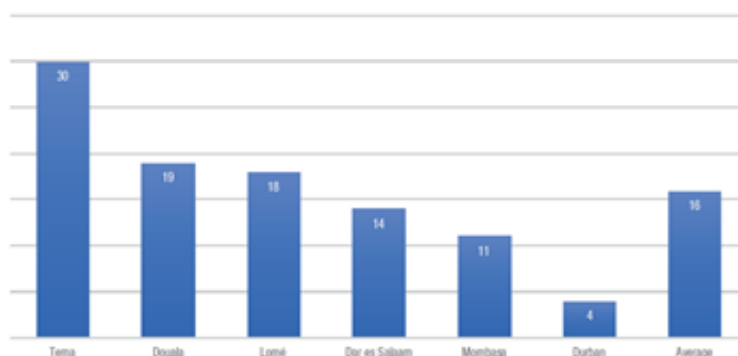


Figure 18: Average Dwell time in Sub-Saharan Africa 2011

Source: UNCTAD (2017)

In 2011, Durban had the lowest average dwell time compared to other ports in the region followed by Mombasa in Kenya with 11 days of dwell time on average. In general, the higher the dwell time results in the complicated planning process and lead to congestion of the yard. A competitive advantage of a port is also on the reduction of dwell time through efficient terminal processes.

4.5 DEA efficiency analysis

The DEA technique has been used by various studies as stated in the literature, where relative efficiency, technical efficiency and scale efficiency of an organisation such as universities, courts, cities, business firms, countries and ports is assessed using (inputs) DMUs concerning output mostly container throughput. DEA is a data-oriented approach used to evaluate the performance of DMUs by converting multiple inputs into outputs (Cooper, Seiford & Zhu, 2004). Since the development of the DEA in 1978 by Charnes, Cooper and Rhodes, many studies have recognised the use of the technique in performance evaluation. The analysis allows the use of real-time data to obtain informed and applicable results, and it can measure the impact of similar inputs on multiple outputs. It enables the evaluation of the effect of multiple inputs of complex and unknown relations between the outputs.

4.5.1 DEA Constraints

DEA is limited in its DMUs inputs to maximise the output level. Therefore it does not thoroughly assess the significance level of each input, such as crane productivity and berth related measures. The input variables have a variety of equipment summed up such, RTGs, RMGs, MHC and yard equipment with different safe working load and speed. These factors are not considered and the availability of the equipment, which could be affected and the berth that may be closed for some time due to upgrade or dredging.

4.6 DEA results

The DMUs selected in this study are 11 container terminals in Africa all striving to hubs in the region, DCT, Mombasa, port of Djibouti, Apapa, Tanger Med port, Dar Es Salaam, Tema, Douala, Lome, Abidjan and Port Said. According to UNCTAD report 2017, containerisation as increased in Africa by 1.1 % from 2016 to 2017. The data used is based on 2017 figures available from the various databases and port authority's websites.

Port Said (Egypt) situated at the Northern entrance of the Gulf of Suez (important shipping route). Port Said is ranked 52 in international container port rankings, and it is the second busiest port in Africa handling 2 989 897 TEUs.

Tanger Med Port, Morocco is set to be the new hub in the Mediterranean. According to Tanger Med port authority, the port is ranked 45th in global container ports rankings and 1st in Africa. The installed throughput capacity is 3 million TEUs; however, in 2017 the port exceeded the capacity by 11% handling 3 122 409 TEUs.

Tanzania Ports Authority owns Dar es Salaam in Tanzania. The port handled 95% of the country's international trade and serving the landlocked countries such as Zambia, Malawi, Burundi, Uganda, Rwanda and the Democratic Republic of Congo. The port links East and Central Africa and Far and the Middle East.

The Port of Tema is the largest port in Ghana handling about 85% of the country's trade. The port's strategical location on the east coast of Ghana making it ideal to be the hub of West Africa. The port of Djibouti is the capital and principal port of the Republic of Djibouti located south of Gulf of Aden in the North Eastern coast of Africa. Mombasa port is a deep-water port, in the second biggest city in Kenya. The port offers consistent feeder services to Durban, Dar es Salaam, Djibouti, Dubai and Salalah. The port under the monitoring and control of Kenya Maritime Authority also serve the similar hinterland as Dar es Salaam, Uganda, Rwanda and Democratic Republic of Congo and Burundi. The port of Doula Cameroon is located between West and Central Africa in the Gulf of Guinea. The port of Abidjan, Cote D'Ivoire is aimed

at becoming leading West Africa's commercial hub. The port serves landlocked countries such as Niger, Burkina Faso and Mali. The port of Lome, Togo is a deep-water port that can accommodate third generation vessels in the West African coast serving Niger, Burkina Faso and Mali. The port of Apapa is the largest port in Nigeria operated by AP Moller. Table 9 shows a summary of input and output variables for the selected DMUs.

Table 9: Summary of input and out variables

DMUs	Input variable						Output Variable
Name of the Port	Berth (No)	Max. Draft (m)	Quay Length (m)	Quay Cranes (No)	Yard Equipment (No)	Storage Capacity (TEUs)	Container Throughput (TEUs)
DCT	8	12,8	2600	20	485	26 000	2 699 978
Mombasa	5	13,5	964	11	331	25 000	1 189 000
Djibouti	2	12,5	400	4	100	16 000	987 000
Apapa	4	13,5	1005	7	138	19 500	491 197
Abidjan	5	11,5	1000	11	31	22000	705 000
Dar Es Salaam	4	12,2	725	6	128	11500	684 100
Port Said	3	13,2	950	9	158	44000	2 989 897
Tema	2	11,5	574	10	64	20000	567 207
Douala	3	8,5	660	5	99	18000	370 000
Lome	6	15,0	950	10	78	10000	238 173
Tanger	8	18	1600	17	231	18 000	3 312 409

Source: Author

4.6.1 Input-oriented Constant Returns to Scale (CRS) efficiency

The CRS results indicate the score of technical efficiency for the ports, where CRS is equal to one (pure technical efficiency) the port is referred as efficient and if CRS less than one then the port is inefficient. Figure 19 illustrates the CRS efficiency scores of the inputs of the ports.

DMU No.	DMU Name	Input-Oriented	Sum of		Optimal Lambdas			
		CRS Efficiency	lambdas	RTS	with Benchmarks			
1	DCT	1,00000	1,000	Constant	1,000	DCT		
2	Mombasa	0,48920	0,379	Increasing	0,208	Port Said	0,171	Tanger
3	Djibouti	0,83551	0,326	Increasing	0,288	Port Said	0,038	Tanger
4	Apapa	0,27327	0,158	Increasing	0,096	Port Said	0,062	Tanger
5	Abidjan	1,00000	1,000	Constant	1,000	Abidjan		
6	Dar Es Salaan	0,50536	0,214	Increasing	0,075	Port Said	0,138	Tanger
7	Port Said	1,00000	1,000	Constant	1,000	Port Said		
8	Tema	0,46100	0,247	Increasing	0,075	Abidjan	0,172	Port Said
9	Douala	0,25875	0,121	Increasing	0,095	Port Said	0,026	Tanger
10	Lome	0,19714	0,074	Increasing	0,024	Port Said	0,050	Tanger
11	Tanger	1,00000	1,000	Constant	1,000	Tanger		

Figure 19: Input-Oriented CRS efficiency

Source: Author

Based on the CRS efficiency level of each terminal, the analysis shows that only four terminals were efficient with a score of 1: DCT, Abidjan, Port Said and Tanger Med port. There remaining terminals are inefficient with a score less than 1. UNCTAD's review of maritime transport (2017), argues that Morocco, Egypt and SA are the best countries with liner connectivity in Africa. Tanger Med port has been ranked as the first busiest port in 2017 because of its strategic location on the Mediterranean as the transshipment hub. The port of Djibouti has benefited from the private investments as Eastern African transshipment hub and geographic location and improved its liner connectivity from 2009 to 2017. Figure 20 shows the Liner connectivity index from 2004 to 2017.

4.6.2 Return to Scale (RTS)

In figure 19 the RTS is determined using the Sum of lambdas, where is equal to 1 then the rule of CRS applies, however, where the Sum of lambdas is greater or less than one then Decreasing Return to Scale (DRS) and Increasing Return to Scale (IRS) applies respectively. Therefore, the four efficient terminals CRS dominates and the IRS terminals, an increase in either in terminal storage capacity, the number of quay cranes, quay length, yard equipment or draft with yield more throughput.



Figure 20: Liner connectivity index

Source: UNCTAD (2017)

4.6.3 Input -oriented CRS Model Slacks

Figure 21 shows the Slack of the input variables. Almawsheki & Shah (2015) in their study found that the efficient terminals reflect zero Slack in the input variables. Likewise, figure 21 illustrates the four efficient terminals with zero Input Slacks. This indicates that their ratio of input variables to output (throughput) is appropriate and resources are used effectively to achieve efficiency. In contrast, Mombasa, Djibouti, Apapa, Dar es Salaam, Tema, Douala and Lome terminals have been relatively inefficient as the effect of the unsatisfactory application of input variable resources.

DMU No.	DMU Name	Input Slacks					Output Slacks	
		Berths	Draft	QL	QC	YE	S C	CT
1	DCT	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
2	Mombasa	0,45183	0,77656	0,00000	0,59793	89,50747	0,00000	0,00000
3	Djibouti	0,50476	5,95941	0,00000	0,10659	29,28839	0,00000	0,00000
4	Apapa	0,31128	1,31198	84,73505	0,00000	8,29676	0,00000	0,00000
5	Abidjan	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
6	Dar Es Salaam	0,68776	2,67790	73,23874	0,00000	20,79014	0,00000	0,00000
7	Port Said	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
8	Tema	0,03056	2,16758	26,12520	2,23604	0,00000	0,00000	0,00000
9	Doulaa	0,28525	0,47945	39,19290	0,00000	4,63109	0,00000	0,00000
10	Lome	0,71063	1,73726	84,30049	0,90390	0,00000	0,00000	0,00000
11	Tanger	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000

Figure 211: Input -oriented CRS Model Slacks

Source: Author

The Slacks indicate that for all the inefficient terminals, their inputs can either be reduced or increased in order to become effective. For example, the efficiency score of Mombasa is 0.48920, which implies that the port should adjust inputs by 0.5108. The slack indicates which inputs to be adjusted, in this case, Mombasa port should adjust the number of berths (0.4518), maximum draft (0.7765), Quay cranes (0.59793) and Yard equipment (89.50747) to be technically efficient. The results for Djibouti, Apapa, Dar es Salaam, Tema, Douala and Lome are interpreted in the same way as Mombasa.

4.6.4 Input-oriented VRS efficiency

The VRS input-oriented efficiency was applied to test the efficiency score of the DMUs. Nine DMUs were found to be efficient (DCT, Djibouti, Abidjan, Dar es Salaam, Port Said, Tema, Douala, Lome and Tanger Med). Mombasa and Apapa's efficiency score is less than one, and therefore they are technical inefficient.

Input-Oriented VRS			Optimal Lambdas							
DMU No.	DMU Name	Efficiency	with Benchmarks							
1	DCT	1,00000	1,000	DCT						
2	Mombasa	0,81925	0,160	Djibouti	0,108	Port Said	0,584	Douala	0,149	Tanger
3	Djibouti	1,00000	1,000	Djibouti						
4	Apapa	0,78722	0,210	Djibouti	0,332	Dar Es Salaam	0,449	Douala	0,009	Lome
5	Abidjan	1,00000	1,000	Abidjan						
6	Dar Es Salaam	1,00000	1,000	Dar Es Salaam						
7	Port Said	1,00000	1,000	Port Said						
8	Tema	1,00000	1,000	Tema						
9	Douala	1,00000	1,000	Douala						
10	Lome	1,00000	1,000	Lome						
11	Tanger	1,00000	1,000	Tanger						

Figure 222: Input-oriented VRS efficiency Score

Source: Author

As shown in figure 22 Mombasa port has an efficiency score of 0.81925. Therefore, the ports inputs should adjust by 0.1875 in order to be technically efficient, and Apapa port should adjust their inputs by 0.21278 units. In contrast to the results obtained using DEA-CRS, the VRS slack results show that Mombasa port should adjust the inputs (number of the berth, quay cranes and yard equipment). On the other hand, the Apapa port should also adjust the inputs (quay length and quay cranes) and output (Container Throughput).

4.6.5 Assessment of Scale of Efficiency

A comparison of the CRS and VRS results indicate that DCT, Abidjan, Port Said and Tanger Med have an efficiency score of one, while Mombasa, Djibouti, Apapa, Dar es Salaam, Tema, Douala and Lome have efficiency score of less than one and therefore rendering them as inefficient under CRS. However, VRS shows that not only DCT, Abidjan, Port Said and Tanger Med have an efficiency score of 1 but also Djibouti, Dar Es Salaam, Tema, Douala and Lome are technically efficient. Table 10 shows the efficiency scores attained by the DMUs under CRS and VRS. After that scale of efficiency is established by dividing CRS over VRS (CRS/VRS) if the scale is one then the port has achieved the Scale of efficiency for the period under review, however,

if the Scale is less than one then the if shows inefficiency of the scale to varying degrees. The RTS is also determined.

Table 10: CRS and VRS comparison

DMU No.	DMU Name	Input-Oriented CRS Efficiency	Input-Oriented VRS Efficiency	Scale Efficiency CRS/VRS	RTS
1	DCT	1,00000	1,00000	1,00000	-
2	Mombasa	0,48920	0,81925	0,59713	increasing
3	Djibouti	0,83551	1,00000	0,83551	increasing
4	Apapa	0,27327	0,78722	0,34714	increasing
5	Abidjan	1,00000	1,00000	1,00000	-
6	Dar Es Salaam	0,50536	1,00000	0,50536	increasing
7	Port Said	1,00000	1,00000	1,00000	-
8	Tema	0,46100	1,00000	0,46100	increasing
9	Douala	0,25875	1,00000	0,25875	increasing
10	Lome	0,19714	1,00000	0,19714	increasing
11	Tanger	1,00000	1,00000	1,00000	-

Source: Author

The scale efficiency indicates DCT, Abidjan, Port Said and Tanger Med have an efficiency scale of one and therefore they are technically efficient. The remaining ports are inefficient; these results are similar to the results obtained under CRS initially.

Despite the above results, it is important to note that this is not a final method as it measures technical efficiency based on the data obtained from secondary sources and only applied quantified variables to measure efficiency. Efficiency varies from time to time based on the combination of variables used, technological improvements, equipment maintenance, labour skills are other factors that should be considered as discussed in the literature review.

Although the results show DCT as efficient, TNPA and TPT have repeatedly reported that performance disturbed by weather conditions and equipment challenges. According to Transnet master plan, berth deepening in DCT in order to accommodate the larger vessels will temporarily reduce the theoretical capacity of 3.4 million TEUs to 3 million and excess vessels will be diverted to the ports in Eastern Cape.

CHAPTER 5: CONCLUSION

In chapter 4, the data was in table form, then in the form of graphs and figures then explained. An analysis of the selected ports was completed using Input-oriented analysis DEA with detailed results. This chapter aims to draw meaningful conclusions and recommendations of the study and provide an overview of the limitations and criticism.

5.1 Major findings

The objective of the research was to evaluate the impact of port efficiency, conduct analyses of the KPIs of the DCT, and contrast the performance indicators of the DCT with international standardised indicators. The study identifies KPIs and their primary importance in the assessment of the level of port performance. The container throughput of the DCT from 2008 to 2017 shows the highest throughput in 2015. The number of container vessel calling DCT has declined gradually from 2014 to 2017; there is no correlation between the vessel traffic and the throughput.

The study found that TPT and TNPA set and monitor different KPIs and their role are different, but they both belong under Transnet as discussed in the study. The operational efficiency measures, anchorage time, SWH, GCH, container dwell time

and BOR. Targets are setting by TPT and TNPA based on the previous year performance, hence the variation of targets from year to year. It is noted that the port has a high anchorage time compared to the desired targets. The deployment of tandem cranes is not fully effective through the crane moves. There are chances of improving the productivity of the port by ensuring the efficient allocation of resources.

Furthermore, the study found that operational efficiency is influenced by factors outside the control of the port such as weather delays and tidal effects. The Durban port is a multipurpose port with a passenger, automotive, containers, liquid bulk cargo and dry bulk terminal; the study was aimed at evaluating DCT performance. Therefore, the data obtained from reports issued by Transnet led to biasness of the performance results in the study as the KPIs are reported as the overall for the port.

An input-oriented DEA model was used to evaluate the efficiency of 11 container ports in Africa. The efficiency scores indicated DCT, Tanger Med port, Port Said and Abidjan as efficient. Contrary to the results, Transnet reported some factors hindering operation efficiencies such as equipment failure, weather and tides. All the inefficient ports show increasing returns to scale.

5.2 Recommendations

In order to achieve the desired SWH and GCH, the equipment needs to be technically and mechanically sound and fully utilised. The significant issues with operational efficiency are equipment downtime, therefore, on a short-term level, constant maintenance is required through intelligent crane management system. It acts, as a diagnostic tool that allows real-time feedback status and detects early warning of equipment failure. It is essential that the personnel be trained and aware of the equipment conditions. There are different forms of maintenance: Planned or preventative maintenance where equipment is inspected to avoid interruption and corrective maintenance is conducted after the equipment breakdown. The use of intelligent crane management system allows for predictive maintenance where the

sensors collect data, and it used to predict the future maintenance based on the historical data.

The long-term solution of replacing all the old equipment, which requires enormous amounts of funds. Proper maintenance of the equipment allows for uninterrupted cargo operations, thereby increasing productivity and equipment lifespan. Another option is applying a simultaneous crane operation for loading and discharging operations a concept that has been tried and tested in the port of Singapore. The cranes operate simultaneously in the yard also with RTG sizes that allow movement over another to enhance the speed of operations. Operators aim should focus more on improving SWH and minimising waiting time and port time through proper crane intensity or deployment of cranes for each vessel.

Training and education is vital to an organisation in ensuring that all the operators have the desired skills to do their allocated duties, therefore, an organisation should have training policies in place. Training does not only enhance efficiency, but it promotes human resource development. If the labour force is well trained, then they can operate the equipment more efficiently and performance is improved. Furthermore, it encourages the employees to perform with confidence as they gain some sense of security and protection of their jobs. All the operators must be continuously encouraged to attend training as planned by the organisation; managers must ensure fairness in rotation of personnel when it comes to training.

In order to cope with the changing in vessel size, the port authorities should consider deepening of the berths from the current draft 12.8 to 15 metres, increasing the capacity of the port and improvement to access of the port through dredging.

Terminal management and port authorities should revise the procedures on reporting and recording of performance indicators for each sector, i.e. time; related KPIs should be separate for containerships, bulks and passenger ships. This will enable easy assessment of performance in each sector. Generally, the waiting time, BOR and port time for bulk ships are affected by different factors compared to containerships.

5.3 Limitations and Criticism of the study

The findings of the study are based on data obtained from the port authorities website. The data obtained are averaged, and therefore it limits the ability of the author to apply other tools to derive a meaningful conclusion for the study. The KPIs are already summarised monthly based on primary data, which was not accessible at the time of the study due to strict and lengthy procedures.

The DEA findings are based on fewer selected DMUs in the African region and caution should be taken when interpreting the results. It should be noted that the data is obtained from the port authority's websites and other credible databases; however, it does not always guarantee that the data is up to date. Several container ports and other factors such as labour, financial indicators and operational time could not be included in the study due to the difficulties in obtaining data.

The current research can be extended in the future by obtaining primary data in the KPIs including labour, operational time and financial indicators. More African ports should be included and data on port connectivity. Furthermore, it would be essential to investigate the efficiency of the SA port structures.

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