ISSN 0554-6397
UDK: 004.032.26
Review article
Received: 26th November 2019

Oluwatoyin Adeola Osundiran
E-mail: 216088926@student.uj.ac.za
Felix Okonta
E-mail: fnokonta@uj.ac.za
Harry Quainoo
E-mail: hquainoo@uj.ac.za
Faculty of Engineering and Built Environment, University of Johannesburg, Auckland Park, 2001, South Africa

The Criticality of Evaluating Port Efficiency Modelling: A Case of 19 Sub Saharan African Ports for the period of 2008-2015.

Abstract

The paper described the essence of evaluating port efficiency using the Data Envelopment Analysis Malmquist Production Index Model. The model was used to examine the drivers of efficiency of 19 Sub-Saharan African Ports for the period of 2008-2015. The importance of ports to the development of nations in Africa makes it expedient to evaluate how efficient ports in sub-Saharan Africa are and what are the drivers of efficiency. The result of the study indicated that the significant drivers of productivity in the ports examined are technical efficiency. A Port continuous improvement framework was developed to assist in improving port performance. The Port continuous improvement framework is essential because the improvement in the port will have a multiplier effect on all the maritime stakeholders and the economy at large.

Keywords: Data envelopment Analysis, Malmquist Production Index, Port Efficiency, Sub-Saharan African Ports, Container Ports, Drivers of Productivity

1. Introduction

The role of maritime ports in the economics of trade and transport is one of importance and complexity [32]. Developing countries continue to account for most global seaborne trade flows, both in terms of exports and imports [50] include African nations, shipped 60 percent of world merchandise trade by sea in 2017 and unloaded

63 percent of this total [50]. In South Africa for example, approximately 96% of the country's exports are conveyed by sea [19]. According to [44], ports are points of convergence between two geographical domains of freight circulation; the land and the maritime domains. Ports form a vital link in the supply chain and, consequently, port efficiency is an important contributor to a nation's international competitiveness. Thus, monitoring and comparing the overall efficiency of national port systems has become an essential part of many countries' microeconomic reform programs. The DEA techniques originate from the seminal work of Farrell (1957) and were later developed, notably by [11] and [2]. The standard approach to the measurement of productivity change over time is the Malmquist index [10, 24, 28]. [31] first introduced the Malmquist total factor productivity index before being further developed in the frame of DEA. [31] defined a quantity index (QI) as ratios of distance functions where observations were evaluated relative to an indifference curve (IC). The Malmquist Production Index Data Envelopment Analysis (MPI-DEA) is an effective tool for evaluating port efficiencies and determining the drivers of port efficiency. The criticality of drivers of efficiency is that it will cause improvement in port efficiencies. DEA is a non-parametric mathematical programming approach to frontier estimation [32]. DEA is a useful tool to investigate the performance of decision-making units (Gregoriou, Gultek and Demirer, 2017). The decision making units are the ports. Transforming decisions can only be made if the ports are equipped with the information to take the correct actions. The objective of this work is to determine the drivers of port productivity and to develop a port continuous improvement framework. Efficiency is the key performance indicator in transport [23]. Measurement and analysis of port efficiency will allow port users to make efficiency comparisons and provide regional and national port operators/regulators with a valuable management tool for making informed decisions on port planning and operations [17]. The subsequent sections will examine the background, methodology, the research results and the final section will end with a discussion and conclusion.

2. Background

This section reveals previous study done on efficiency. The review of literature indicates that ports in Western Europe, North America and East Asia have for many years utilised efficiency analysis to improve operations by minimising the use of resources for production. Port efficiency has fuelled port growth and massive investment in port related activities [51]. Container throughput is one of the most important parameter for evaluating the competitive strength of ports [30]. Container terminals' efficiency is often associated with productivity and performance [38]. Container throughput is an important element of port productivity [51]. DEA is also an essential tool for measuring port efficiency and is an alternative methodology to those used by many studies [6]. Port efficiency analyses the ability of a port to obtain the maximum output under a given amount of inputs or with the minimum amount of inputs under a given amount of outputs [47]. Many studies have been conducted on using DEA for ports and Table 1 captures the application of DEA in the port sector. The table reveals the author and year of publication in journals, methods used, inputs, outputs, the DMUs and the period examined. The review of literature in DEA indicated its application numerously in Asia, America, Latin America, Europe and North America, but few studies in Africa.

Table 1: Taxonomy of Application of DEA in the Ports Industry

Author/Year	Title of Journal Article	Methods	Observation	Period	DMU
Roll and Hayuth 1993	Port Performance Comparison Applying Data Envelopment Analysis	DEA	Hypothetical 20	1993	Ports
Barrend Mienie, Gary Sharp, Warren Bretteny, 2017	Ranking Selected Container Terminals in Africa Using Data Envelopment Analysis	DEA MPI	15	2013-2014	African Ports
NG S.F and Chee Xui Lee,2007	Productivity Analysis of Container Port In Malaysia: A DEA Approach	DEA	6	2000-2005	Malaysia Ports
Anguibi China Flora Carine, 2015	Analysing the Operational Efficiency of Container Ports in Sub-Saharan Africa	DEA	16	2012	Sub Saharan Africa
Ahmed Salem Al-Eraqi Adli Mustafa Ahamad Tajudin,2010	An Extended DEA Windows Analysis: The Middle East and East African Seaports	DEA	22	2000-2005	The Middle East and East Africa
Halvor Schøyen and James Odeck,2013	The Technical Efficiency of Norwegian Container Ports: A Comparison to Some Nordic and UK Container Ports Using DEA	DEA	24	2002-2008	Nordic Ports and the United Kingdom
Cullinane, Song, Ji and Wang (2004)	An Application of DEA Windows Analysis to Container Port Production Efficiency	DEA	30	1992-2000	Top 30 Container Port
Nikola Kutin, Thanh Thuy Nguyen and Thomas Vallee (2017)	Relative Efficiencies of ASEAN Container Ports Based on DEA	DEA	50	2014	Asian Container Port
Hanaa Abdelaty Hasan Esmail, 2016	Efficiency Assessment of Jazan Port Based on Data Envelopment Analysis	DEA	9	2000-2014	King Saudi Arabia Port

Hong Gao, Liang LV, Wei Liu, 2010	Efficiency Measurement of Schenzen Port Using Data Envelopment Analysis	DEA	1	2003-2008	Schenzen Port
Tongzon Jose,2001	Efficiency Measurement of Selected Australian and Other International Ports Using Data Envelopment Analysis	DEA	16	1998	Australian Ports
George Kobina van Dyck,2015	Assessment of Port Efficiency in West Africa Using Data Envelopment Analysis	DEA	6	2006-2012	West Africa
Ramon Nunez-sanchez and Pablo Coto Milan,2012	The Impact of Public Reforms on The Productivity of Spanish Ports: A Parametric Distance Function Approach	DEA	27	1986-2005	Spanish
Nwanosike O.F Nicoleta S. Tipi and David Warnock-Smith,2016	Productivity Change in Nigerian Seaports After Reform: A Malmquist Production Index Decompositon Approach	MPI DEA	6	2000-2011	Nigerian
Fu Boxin, Song Xiang Quin and Guo Zi-Jian (2009)	DEA-Based Malmquist Productivity Index Measure of Operating Efficiencies: New Insights With an Application to Container Ports	MPI DEA	10	2001-2006	China
Juan Jose Diaz Hernandez, Eduardo Martinez-Budria and Sergio Jara-Diaz,2008	Productivity in Cargo Handling in Spanish Ports During a Period of Regulatory Reforms	MPI DEA	21	1994-1998	Spanish
Okeudo G.N, 2013	Measurement of Efficiency Level in Nigerian Sea Port After Reform Policy Implementation. The Case Study of Onne and Rivers Seaport	DEA	2	2001-2010	Onne and Rivers
Bogusz Wisnicki, Leszek Chybowski, Maksymilian Czarnecki, 2017	Analysis of the Efficiency of Port Container Terminals with the use of DEA Method or Relative Productivity Evaluation	DEA	9	2014	European Port

Danijela Pjevcevic, Aleksandar Radonjic, Zlatko Hrle, Vladeta Colic 2012	DEA Window Analysis for Measuring Port Efficiencies in Serbia	DEA Window Analysis	5	2001-2008	Serbian
Joanna Baran and Alexsandra Gorecka, 2015	Seaport Efficiency and Productivity based on DEA and MPI	MPI DEA	18	2012	18th world leading container port 2012
Tetteh Evans Ago, Yang Hualong, Gomina Mama Fousseni 2016	Container Ports Throughput Analysis: A Comparative Evaluation of China and Five West African Countries	DEA	6	2008-2013	West Africa and China
Peter Wanke, Rafael Garcia Barbastefano and Maria Fernanda Hija, 2011	Determinants of Efficiency at Major Brazilian Port Terminals	DEA and SFA	25	2009	Brazillian Ports
Carlos Pestana Barros,2012	Productivity Assessment of African Sea Ports	DEA MPI	23	2004-2010	Nigeria, Mozambique and Angola
K.M Chudasama and Kiran Pandya, 2008	Measuring Efficiency of Indian Ports: An Application Of DEA	DEA	12	2000-2006	India
Yongrok Choi, 2011	The Efficiency of Major Ports Under Logistics Risk In North East Asia	DEA MPI	13	2005-2007	China, Korea and Taiwan
Bo Lu Nam Kyu Pak and Yunfu Huo, 2015	The Evaluation of The Operational Efficiency of the World's Leading Container Seaports	DEA	20	2012	World Leading container ports
Kevin Cullinane and Tengfei Wang 2010	The Efficiency Analysis of Container Ports Production Using DEA Panel Data Approaches	DEA Window Analysis	25	2010	Leading container ports
Fanou E.H and Wang X 2018	Assessment of Transit Transport Corridor Efficiency of Landlocked African Countries Using DEA	DEA	15	2008-2013	Landlocked African countries
Nadir Gurpinar and Hasret Benar Balcioglu, 2018	Impact of Famagusta Port Efficiency on North Cyprus	DEA	1	2010-2015	Port of Famagusta

Estache, A., Tovar de La Fe. Trujillo L., (2004)	Sources of Efficiency Gains in Port Reform: A DEA Decomposition of a Malmquist TFP Index For Mexico.	DEA MPI	11	1996-1999	Mexican ports
Cheon S., Dowall D.E., Song D (2010)	Evaluating Impacts of Institutional Reforms on Port Efficiency Changes: Ownership, Corporate Structure, and Total Factor Productivity Changes Of World Container Ports	DEA-MPI	98	1991-2004	World Container Ports

Source: Osundiran, 2018.

Since over 80 per cent of world merchandise trade in volume terms is handled by ports worldwide and nearly two thirds of this trade are loaded and unloaded in the ports of developing countries, the strategic importance of well-functioning and efficient ports for growth and development cannot be overemphasized [50]. Due to the volume of shipment that passes through African ports it is important that African seaports be efficient.

African seaport efficiency is vital to businesses that import and export via seaports, specifically into and out of Africa. Therefore, to be a significant force in global trade, it is crucial that existing maritime supply chains to and from South Africa and any other African country function as efficiently as possible and new efficient supply chains develop [26]. Most importantly, in addressing the efficiency problem in a modern port system, one must identify the logistics and cross functional drivers operating in the port system supply chain [41]. Malmquist Production Index DEA model is used to evaluate the levels of performance along supply chains and help managers identify weaknesses to improve the overall functioning of the chains.

3. Methodology

The method adopted in this research is exploratory as it is designed to determine the drivers of the productivity for the 19 Sub Saharan African Ports that are located in the sub-Saharan part of Africa. They represent nine countries in sub-Saharan Africa namely: Ghana (Port Tema and Takoradi), South Africa (Transnet Ports include Cape Town, Coega, Durban, East London, Port Elizabeth and Richards bay), Tanzania (Port of Dar es Salaam), Namibia (Port of Lüderitz and Walvis Bay), Mozambique (Port of Beira, Maputo and Nacala), Mauritius (Port of Port Louis), Djibouti (Port of Djibouti and Djibouti container terminal), Nigeria (Tin Can Island Port) and Kenya (Port of Mombasa). These countries represent Southern Africa (Mozambique, Namibia and South Africa), Eastern Africa (Djibouti, Kenya and Tanzania), West Africa (Nigeria and Ghana) and the Indian Ocean (Mauritius). In this research, the DEA empirical analysis uses one output, which is the container throughput. The four inputs used include the number of berths, the number of cranes, number of tugs and the length of quays. The data sources were obtained from key individuals in the selected sub-Saharan African ports and also from port websites. Figure 1 captures the countries represented in the study.

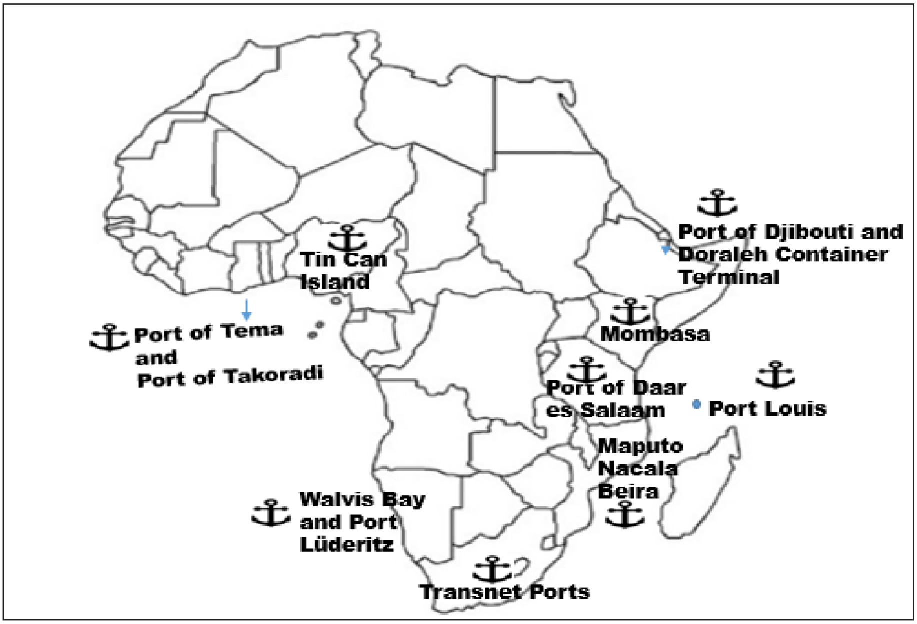

Figure 1: The Selected Ports in the Sub-Saharan African countries
Source: Osundiran, 2019.

According to [28], the Malmquist index decomposes productivity change into two components: Catch-up which captures the change in technical efficiency over time, and Frontier-shift, which captures the change in technology occurring over time. The Malmquist index is a geometric mean of two indices, evaluated concerning period t and period t+1 technologies [24]. Figure 2, graphically illustrates the frontier shift which is as a result of change in technology. This is the change in frontier a to frontier b. C1 and C2 displays a movement upward on the frontier. This is caused because of change in efficiency or the catch –up effect.

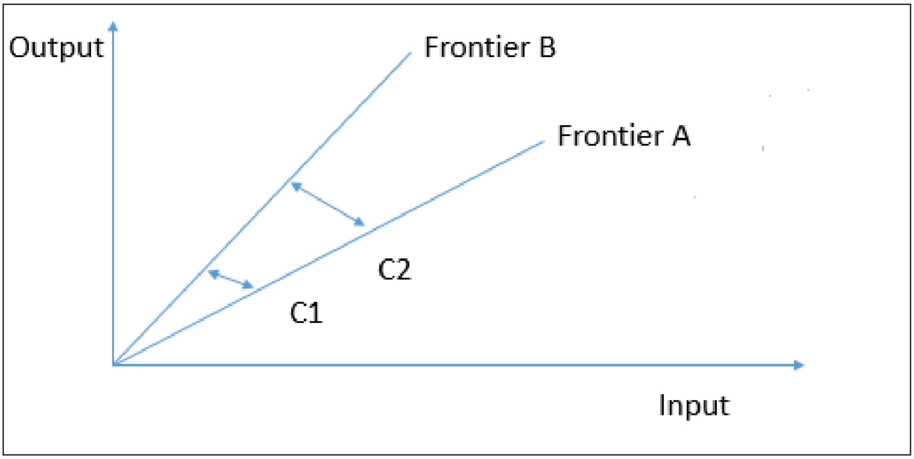

Figure 2: Decomposition of Malmquist Productivity Index
Source: Adapted by, Osundiran, 2018.

Figure 3, illustrates the Malmquist equation that measures efficiency. The product of efficiency change and the technological change makes up the MPI

$$M(Y_{t+1},X_{t+1},Y_t,X_t) = \underbrace{\frac{D^t(Y_{t+1},X_{t+1})}{D^t(Y_t,X_t)}}_{\text{Efficiency change}} \underbrace{\left[\frac{D^t(Y_{t+1},X_{t+1})}{D^{t+1}(Y_{t+1},X_{t+1})} X \frac{D^t(Y_t,X_t)}{D^{t+1}(Y_t,X_t)}\right]^{1/2}}_{\text{Technological Change}}$$

Figure 3: Malmquist Production Index
Source: Malmquist, 1953

Where:

X_t and X_{t+1}	input vectors of dimension at time t and t +1
Y_t and Y_{t+1}	corresponding k- output vectors
D_t and D_{t+1}	denote an input
D(x,y)=	max(ρ:($s/\rho s \in L(y)$) (1)

- Where L(y) represents the number of all input vectors with which a certain output vector y can be produced, that is L(y) = (x:y can be produced with x).
- P in equation (1) can be understood as a reciprocal value of the factor by which the total inputs could be maximally reduced without reducing output.
- Malmquist Production Index (M) = measures the productivity change between periods t and t+1. Productivity declines if M<1, remains unchanged if M=1 and improves if M>1.

4. Research results

The Malmquist Production Index was used because it deals with efficiency over time, instead of examining the snapshot of performance at one specific time. MPI considers performance (changes) across different time periods [39]. The Malmquist model captures the variations in the port performances in the selected ports over a period. In the computation of DEA MPI, two significant issues are emphasised, firstly it is the efficiency catch up also known as technical efficiency and the boundary shift technological change, which is also known as the technology change. The Malmquist model allows for the determination of the drivers of productivity which could be efficiency or technology.

4.1. Technical Efficiency or Catch-up Effect

Efficiency could be enhanced by special initiatives in the firm that have enabled it to change and improve its performance relative to that of the other firms (Bogetoft and Lars, 2010). All the ports reveal changes in their efficiency levels in the years examined. Technical Efficiency change (TEC) is linked to managerial efficiency that causes movement upward or downwards on the production possibility frontier. Hence, ports that have TEC=1 are static regarding efficiency level, therefore revealing no improvement. Ports with TEC>1 indicate improvement in efficiency levels while ports with TEC<1 denote a decline in efficiency level. Figure 4, describes the results. On the average with regards to technical efficiency change, the Port of East London, Port of Durban, Port of Port Elizabeth, Port of Cape Town, Port of Dar es Salaam, Port of Walvis Bay, Port of Port Louis Mauritius, Port of Nacala, Port of Tema, Port of Takoradi, Tin Can Island Port, Port of Mombasa and Port of Maputo had an efficiency level of 1 which means that there is still room for improvement with regards to technical efficiency or catch-up effect. They are all on the borderline of 1. All other ports such as the Port of Lüderitz, Djibouti Container Terminal and Port of Djibouti reveal less than one. This indicates much room for improvement as far as technical efficiency is concerned. The Port of Coega in 2009-2010; Port of Richards Bay in 2012-2013, Port of Beira 2008-2009, 2010-2011, Port of East London 2014-2015 had an efficiency change greater than one These technical efficiency change was once off and not consistent.

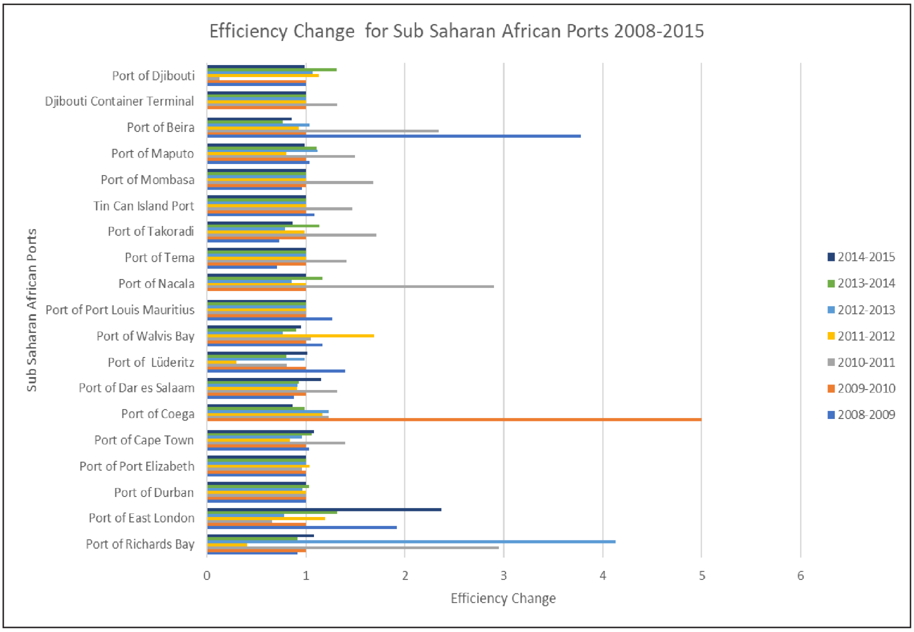

Figure 4: Efficiency Change or Catch-up Effect for Sub Saharan African Ports 2008-2015
Source: Osundiran's Calculations, 2017

4.2. Technology Change

The second aspect of the Malmquist Productivity Index is technological change. This is evaluating the ports based on improvement in technology. With regards to technological change, values above 1 represent technological progress in the sense that more can be produced using fewer resources [7]. Technology change (TC) causes an outward shift in the production frontier. When ports have TC=1, then there is no improvement in technology. When TC<1 then there is a need for technological advancement. Figure 5 illustrates the results of a technological change.

Concerning technology change, on the average for the eight years, the Port of Durban, Port of Dar es Salaam, Port of Walvis Bay, Port of Tema, Port of Takoradi, Tin Can Island Port and the Port of Djibouti have TC=1. This is an indication for more improvement in technology. This is because they are on the borderline of 1. Port of Richards Bay, Port of East London, Port of Port Elizabeth, Port of Cape Town, Port of Coega, Port of Lüderitz, Port of Port Louis Mauritius, Port of Nacala, Port of Mombasa, Port of Maputo, Port of Beira and Djibouti Container Terminal scored less than one hence there is more room for technological changes at these ports. None of the ports had

TC>1 during the year examined. Though some ports indicated a slight increase where TC=1.3. This increase is negligible and productivity was not technologically driven.

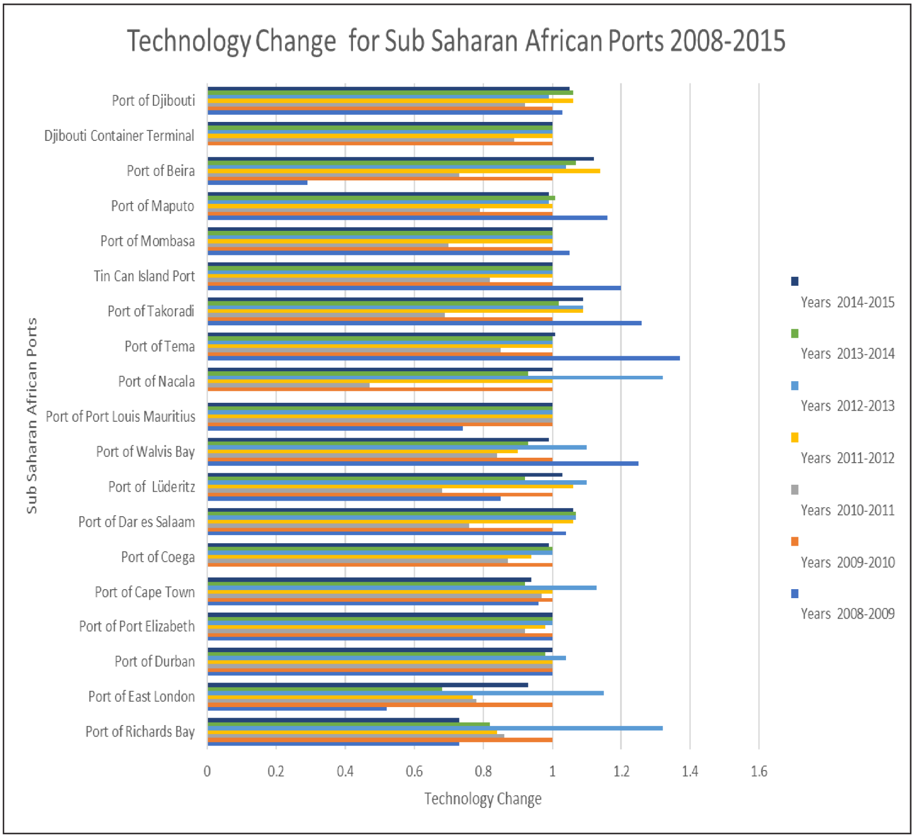

Figure 5: Technology Change for Sub Saharan African Ports 2008-2015
Source: Author's Calculations, 2017

4.3. Malmquist Production Index

The product of TC and EC the Malmquist productivity index. Where the MPI>1 means there is progress in productivity, where MPI<1 signifies a decline in productivity and where MPI=1 indicates stagnancy. Figure 6, provides the MPI results for the ports. For the year 2008-2009, ports of Richards Bay, Cape Town, Coega, Dar es Salaam, Port Louis, Nacala, Tema, Takoradi and Djibouti Container Terminal ports had MPI<1, this indicates a decline in productivity. The ports of East London, Durban and Port Elizabeth had MPI=1 which indicates stagnancy regarding productivity and the ports of Lüderitz, Walvis Bay, Tin Can Island Port, Mombasa, Maputo, Beira and Djibouti have MPI>1 an indication of progress in productivity. For the year 2009-2010, almost all the ports had MPI=1 an indication of stagnancy. However, the port of Coega had an exceptional high MPI level that is greater than 1.

For the year 2010-2011, Port of East London, Port of Port Elizabeth, Port of Lüderitz, Port of Walvis Bay, and the Port of Djibouti had MPI<1 an indication of decline in productivity. However, Port of Durban, Port of Dar es Salaam and the Port of Port Louis Mauritius has MPI=1 a show of stagnancy regarding productivity. Other ports such as Port of Richards Bay, Port of Cape Town, Port of Coega, Port of Nacala, Port of Tema, Port of Takoradi, Tin Can Island Port, Port of Mombasa, Port of Maputo, Port of Beira and Djibouti Container Terminal have MPI>1, which is an indication of productivity.

For the year 2011-2012, MPI<1 for the ports of Richards Bay, East London, Cape Town, Dar es Salaam, Lüderitz and Maputo is an indication of decline in productivity. The ports of Durban, Port Louis, Nacala, Tema, Tin Can Island, Mombasa and Djibouti Container Terminal had MPI=1 an indication of stagnancy. The Port of Port Elizabeth, Port of Coega, Port of Walvis Bay, Port of Takoradi, Port of Beira, and the Port of Djibouti had MPI>1 an indication of progress.

For the year 2012-2013, the Port of East London, Port of Dar es Salaam, Port of Walvis Bay and the Port of Takoradi has MPI<1 an indication of decline in productivity. However, the Port of Port Elizabeth, Port Louis, Port of Tema, Tin Can Island, Port of Mombasa and Djibouti Container Terminal had MPI=1, which depicts stagnancy in productivity. However, MPI>1 for the Port of Richards Bay, Durban, Cape Town, Coega, Lüderitz, Nacala, Maputo, Beira and the Port of Djibouti, an indication of progress in productivity.

For the year 2013-2014, Port of Richards Bay, Port of East London, Port of Cape Town, Port of Coega, Port of Lüderitz, Port of Walvis Bay and the Port of Beira had MPI<1 a decline in productivity. MPI=1 for the Port of Port Elizabeth, Port of Dar es Salaam, Port of Port Louis, Port of Tema, Tin Can Island Port, Port of Mombasa and Djibouti Container Terminal an indication of stagnancy in port productivity. MPI>1 for the ports Durban, Nacala, Takoradi, Maputo and the Port of Djibouti. This constitutes evidence of port productivity for these ports.

For the year 2014-2015, Port of Richards Bay, Port of Coega, Port of Walvis Bay, Port of Takoradi, Port of Maputo and the Port of Beira had MPI<1. This indicated a decline in productivity levels. However, MPI=1 for the ports of Durban, Port Elizabeth, Port Louis, Nacala, Tin Can Island Port, Port of Mombasa and Djibouti Container Terminal. This indicated stagnancy in productivity. Port of East London, Port of Cape Town, Port of Dar es Salaam, Port of Lüderitz. Port of Tema, Port of Djibouti had MPI>1, an indication of an increase in port productivity.

For the ports examined, during the period of 2008-2015, the drivers of productivity are technical efficiency and catch-up effect and not technology. Technical efficiency has played a considerable role in improving the productivity levels of ports; however, technology has not performed a significant role in developing the productivity levels of the ports examined. This may be due to the inability of the ports to employ state of the art technology that is necessary to boost productivity. Hence, there is the need to utilise technology more so as to boost efficiency and productivity amongst the ports.

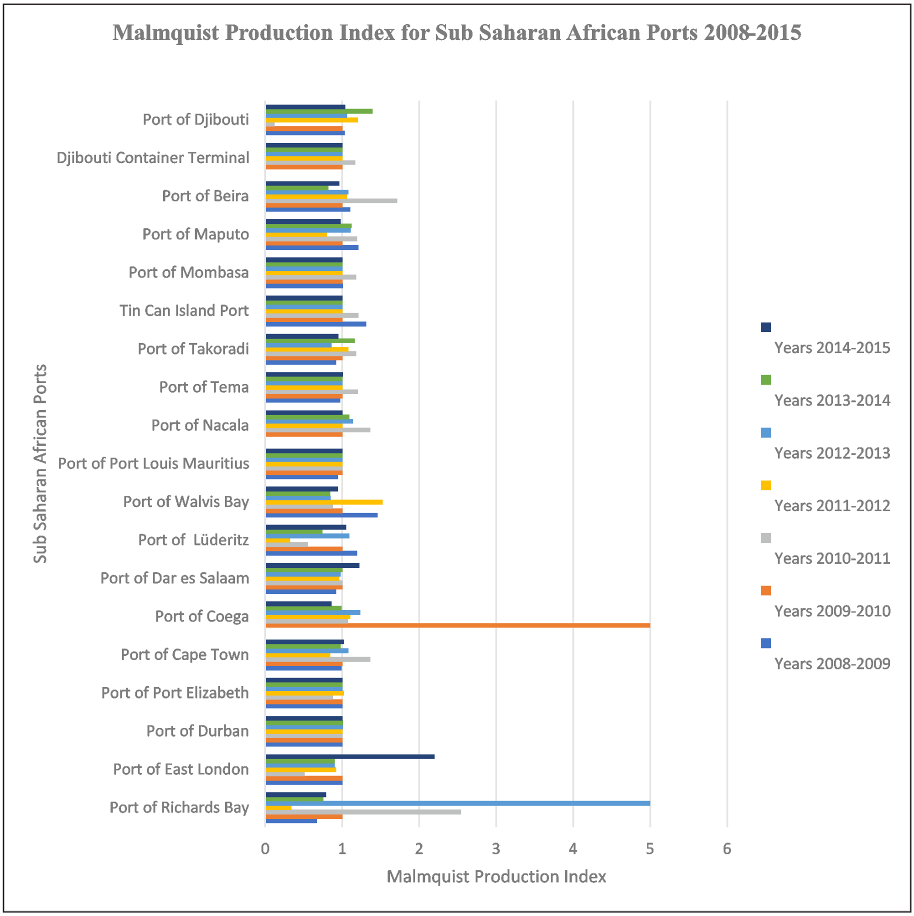

Figure 6: Malmquist Production Index for Sub Saharan African Ports 2008-2015
Source: Author's Calculations, 2017

4.4. Port Continuous Improvement Framework

The port continuous improvement framework is a generic conceptual tool that serves as a guide to maritime stakeholders. This generic framework is designed to assist ports in improving their efficiency levels continually. Inefficient ports as identified from the research must engage the maritime stakeholders in a forum that outlines expectations and reality. A discussion that addresses the needs and expectations of the port users' vis-a-vis the specific port concerning issues such as port systems, service level agreement, structures and skilled staff are used to ensure the success of the process. Firstly, the port continuous improvement framework identifies the efficiency level. The port can engage port consultants or port researchers to ascertain the port's level of efficiency. Container throughput is one of the indicators of efficiency. The quantitative data from the container throughput can be evaluated month by month or annually to assess the incidence of fluctuations. This is a pointer to inefficiency though it may not be exact without still an additional study of the port peculiarity. The port staff can be trained on the application of DEA to evaluate port efficiency. Secondly, a forum for engaging the maritime stakeholder is also essential. Effective collaboration between the stakeholders is encouraged to enhance productivity and efficiency. Expectations of port users vis-à-vis the actual. An active panel will lead to the third stage which is the identification of critical transportation parameters or efficiency indicators that both stakeholders agree on. Structures will be established to improve and implement the critical transportation parameters or efficiency indicators. No matter how automated the port may be, it is the workforce available that determines the efficiency and efficacy of the port [5]. The framework cannot be successful without well-motivated, rewarded and trained port employees. Finally, an introduction of the port efficiency application software could augment performance. This software is developed to ensure that required levels of efficiency are met. It is also serving as a tool that is made available to all maritime stakeholders to ensure competitiveness among the ports.

5. Conclusion and Recommendation

The DEA based MPI was used to determine the drivers of productivity change at the ports. This was to find if changes in productivity can be attributed to technical efficiency or technology change. However, the results have illustrated that ports in sub-Saharan African utilise technical efficiency more to drive productivity than technology. Hence, there is room to explore how technology can drive the productivity levels of ports. For the selected ports in sub-Saharan Africa, the driver of productivity is technical efficiency and not technology. This means that there is a need for ports in sub-Saharan Africa to engage in technology. Port efficiency evaluation is critical to ports in Africa [42].

6. References

1. Ahmed Salem Al-Eraqi Adli Mustafa Ahamad Tajudin Khader (2010). An Extended DEA Windows Analysis: Middle East and East African Seaports. *Journal of Economic Studies*, Vol. 37 (2), pp. 208 – 218. Available at: http://dx.doi.org/10.1108/01443581011043591 [Accessed 31 10 2016].
2. Banker, R.D., Charnes, A. and Cooper, W.W.(1984). Some Models for Estimating Technical and Scale Inefficiencies Data Envelopment Analysis. *Journal of Management Science*. Vol 30. (9), September,

3. Baran, J. and Gorecka, A. (2015). Seaport Efficiency and Productivity Based on DEA and Malmquist Productivity Index. *Logistics and Sustainable Transport*, Vol.6, (1), November, pp. 25-33. Doi: 10.151/jlst-2015-0008. [Accessed13 April 2017].
4. Barros, C.P. (2012). Productivity Assessment of African Seaports. *African Development Review*, Vol. 24 (1), pp.67-78.
5. Bestenbreur, T.A. (2012). Stellenbosch University Masters Class Notes: Terminal Operations.
6. Blonigen, B.A. and Wilson, W.W. (2006). *New Measures of Port Efficiency Using International Trade Data*. NBER Working Paper No. 12052. (DOI): 10.3386/w12052. https://www.nber.org/papers/w12052 [Accessed 3 July 2019]
7. Bogetoft, P. and Otto, L. (2011). Benchmarking with DEA, SFA, and R. *International Series 1 in Operations Research & Management Science,* Vol.157, Available at: http: dx.doi.org/ 10.1007/978-1-4419-7961-2 [Accessed 03 07 2019].
8. Bo-xin F, Song, X. and Guo, Z. (2009). DEA-based Malmquist Productivity Index Measuring of Operating Efficiencies: New Insights With an Application to Container Ports. *Journal of Shanghai Jiaotong University*, Vol. 14 (4), p.490.
9. Carine, A.C.F. (2015). Analyzing the Operational Efficiency of Container Ports in Sub-Saharan Africa. *Open Journal of Social Sciences*, Vol.3, pp.10-17. Available at: http://dx.doi.org/10.4236/jss.2015.310002 [Accessed 31 10 2017].
10. Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity. *Econometrica,* Vol.50, pp. 1393-1414.
11. Charnes, A., Cooper, W.W. and Rhodes, E. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operations Research*, Vol.2, pp. 429-444.
12. Chen, H., Daugherty, P. and Landry, T.(2009). Supply Chain Process Integration: A Theoretical Framework, Vol 30(46)DO - 10.1002/j.2158-1592.2009.tb00110.x [Accessed 12 11 19] JO - Journal of Business Logistics
13. Chen, S., Jeevan, J. and Cahoon, S. (2016). Malaysian Container Seaport Hinterland Connectivity: Status, Challenges and Strategies. *The Asian Journal of Shipping and Logistics*, Vol.32(3), pp. 127-137. Available at: http://dx.doi.org/10.1016/j.ajsl.2016.09.001 [Accessed 31 10 2017].
14. Cheon, S., Dowall, D.E. and Song, D. (2010). Evaluating Impacts of Institutional Reforms on Port Efficiency Changes: Ownership, Corporate Structure, and Total Factor Productivity Changes of World Container Ports. *Transportation Research*, pp.546-561.
15. Chudasama, K.M. and Pandya, K. (2008). Measuring Efficiency of Indian Ports: An Application of DEA. *The ICFAI University Press Journal of Infrastructure.* Vol VI, No2 PP1-21
16. Cullinane, K and Wang , T (2010). *The Efficiency Analysis of Container Port Production Using DEA Panel Data Approaches*. [Accessed 29 08 2016] DOI: 10.1007//s00291-010-0201-70
17. Cullinane, K. and Wang, T.F. (2007). Devolution, Port Governance and Port Performance. *Research in Transportation Economics*, Vol.17, pp.517-566. Available at: http://dx.doi.org/10.1016/S0739-8859(06)17023-7 [31 10 2017]
18. Cullinane, K., Song, D.W. and Ji, P. and Wang, T.F. (2004). An Application of DEA Windows Analysis to Container Port Production Efficiency. *Review of Network Economics*, Vol.3, (2), June, 184-206 https://www.researchgate.net/publication/311344362_An_application_of_DEA_windows_analysis_to_container_port_production_efficiency [Accessed 22 October 2016].
19. De Villers, G., Nieman, G. and Nieman, W. (2017). *Strategic Logistics Management*, 2nd ed. Johannesburg: Van Schaik Publishers.
20. Diaz-Hernandez, J., Martinez-Budria, E. and Jara-Diaz, S. (2008). Productivity in Cargo Handling in Spanish Ports During a Period of Regulatory Reforms. *Networks & Spatial Economics*, Vol.8 (2/3), pp. 287-295. https://link.springer.com/article/10.1007/s11067-007-9056-1 [Accessed 20 September 2017].
21. Esmail, H (2016). Efficiency Assessment of Jazan Port Based on Data Envelopment Analysis. *Mediterranean Journal of Social Sciences*, Vol. 7 No (3), pp 320-327Doi:10.5901/mjss.2016.v7n3s1p320.
22. Estache, A., Tovar de La Fe B. Trujillo, L. (2004). Sources of Efficiency Gains in Port Reform: A DEA Decomposition of a Malmquist TFP Index for Mexico. *Utility Policy*, Vol.12, pp 221-230.
23. Fanou, E.H., Wang, X. (2018). Assessment of Transit Transport Corridor Efficiency of Landlocked African Countries Using Data Envelopment Analysis. South African Journal of Science

Vol.114(1/2), pp. 1-7 Available at: http://dx.doi.org/10.17159/ sajs.2018/20160347 [Accessed 31 10 2018].

24. Färe, R., Grosskopf, S., Norris, M. and Zhang, Z. (1994). Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries, The American Economic Review, Vol. 84 (1), pp. 66-83.
25. Gao, H., Liang, L.V. and Liu, W. (2010). Efficiency Measurement of Shenzhen Port Using DEA. Pages 1-4 Accessed 31 10 2018 Available: https://www.researchgate.net/publication/238517260_Efficiency_measurement_of_Shenzhen_port_using_data_envelopment_analysis
26. Goedhals-Gerber, L.L. (2016). The Composite Supply Chain Efficiency Model: A Case Study of the Sishen-Saldanha Supply Chain. Journal of Transport and Supply Chain Management, Vol.10(1), pp1-13.
27. Gurpinar, N. and Balcioglu, H.B. (2018). Impact of Famagusta Port Efficiency on North Cyprus. *Revista De Cercetare Și Intervenție Socială,* Vol.60, pp143-156
28. Huguenin, J. (2012). Data Envelopment Analysis: A Pedagogical guide for Decision Makers in the Public Sector. City: Lausanne IDHEAP-Cahier 276/2012. Available at: https://serval.unil.ch/resource/serval:BIB_0FC432348A97.P001/REF [Accessed 22 August 2017].
29. Kutin, N., Nguyen, T. and Vallee, T. (2017) Relative Efficiencies of ASEAN Container Ports based on Data Envelopment Analysis. *The Asian Journal of Shipping and Logistics.* Vol.33(2), pp.67-077. Available at: http://dx.doi.org/10.1016/jajsl.2017.06.04 [Accessed 31 10 2018].
30. Liu, L. and Park, G. (2011). Empirical Analysis of Influence Factors to Container Throughput in Korea and China Ports. *The Asian Journal of Shipping and Logistics*, Vol. 127 (2), pp. 279-304
31. Malmquist, S. (1953). Index Numbers and Indifference Surfaces. *Trabjos de Estatistica*, Vol.4(2), pp.209-242.
32. Merkel, A. and Holmgren, J (2017). Dredging the Depths of Knowledge: Efficiency Analysis in the Maritime Port Sector. *Transport Policy,* Vol.60, pp.63-74. Available at: http://dx.doi.org/10.1016/j.tranpol.2017.08.010 [Accessed 06 06 2016].
33. Mienie, B., Sharp, G. and Bretteny, W. (2017). Ranking Selected Container Terminals in Africa Using Data Envelopment Analysis. Management Dynamics, Vol. 26 (1),
34. Nam B.L K Pak and Y. Huo (2015). The Evaluation of Operational Efficiency of the World's Leading Container Seaports. *Journal of Coastal Research*, SI 73, pp. 248-254
35. NG A. S. F and Lee C.X (2007). Productivity Analysis of Container Port in Malaysia: A DEA Approach. Journal of the Eastern Asia. Society for Transportation studies. Vol 7, 2007. 2940-2952
36. Núñez-Sánchez, R, and Coto-Millán, P. (2012). The Impact of Public Reforms on the Productivity of Spanish Ports: A Parametric Distance Function Approach. *Transport Policy*, Vol.24, pp. 99-108. https://doi.org/10.1016/j.tranpol.2012.07.011 [Accessed 20 September 2017].
37. Nwanosike, F.O., Tipi., N.S. and Warnock-Smith (2016). Productivity change in Nigerian seaports after reform: A Malmquist productivity index decomposition approach. *Maritime Policy & Management*, Vol.43(7), pp.798-811. DOI: 10.1080/03088839.2016.1183827
38. Nyema, M.S. (2014). Factors Influencing Container Terminals Efficiency: A Case Study of Mombasa Entry Port. *European Journal of Logistics Purchasing and Supply Chain Management*. Vol. 2 (3) pp. 39-78.
39. Ohene-Asare, K. (2016). Applied Data Envelopment Analysis in Performance Management. Presented at the Stellenbosch Business School, DEA Workshop May 2018.
40. Okeudo, G.N. (2013). Measurement of Efficiency Level in Nigerian Sea Port After Reform Policy Implementation. Case Study of Onne And Rivers Seaport. *IOSR Journal of Business and Management,* Vol.12, (5), pp.46-55. Available at: www.iosrjournals.org [Accessed 31 10 2017].
41. Onyemechi C. (2013) Port Efficiency Modelling in the Post Concessioning Era: The role of Logistics drivers, Agile ports and other perspectives.
42. Osundiran A.and Okonta F (2018) Malmquist Data Envelopment Analysis as a tool to evaluate the productivity levels of container ports in developing countries located in east and southern Africa. Central European Review of Economics and Management. Vol 2 No 3 pages79-97.
43. Pjevcevic, D., Radonjic, A., Hrle, Z. and Colic, V. (2012). DEA Window Analysis for Measuring Port Efficiencies in Serbia. *PROMET-Traffic & Transportation*, Vol.24, pp. 63-72.
44. Rodrigue, J.P., Slack, B. and Notteboom, T. (2013). "Port Terminals" Available at: https://people.hofstra.edu/geotrans/eng/ch4en/conc4en/ch4c3en.html [Accessed online 31 10 2017].
45. Roll, Y. and Hayuth, Y. (1993). Port Performance Comparison Applying Data Envelopment

Analysis (DEA). *Maritime Policy and Management*, Vol. 20, pp. 161-163. Available at: http://dx.doi.org/10.1080/03088839300000025 [Accessed 31 10 2017].

46. Schoyen, H., and Odeck. J. (2013). The Technical Efficiency of Norwegian Container Ports: A Comparison to Some Nordic and UK Container Ports Using DEA. *Maritime Economics and Logistics*, Vol.15, pp.197-221. Doe: 10.1057/mel.2013.3
47. Suárez-Alemán, A., Morales-Sarriera, J., Serebrisky, T. and Trujillo, J. (2016). When it Comes to Container Port Efficiency, Are All Developing Regions Equal? *Transportation Research* Part A 86, pp.56–77. Available at: http://dx.doi.org/10.1016/j.tra.2016.01.018 0965-8564/_ 2016 [Accessed 31 10 17].
48. Tetteh, E, A., Yang, H., and Gomina Mama, F. (2016). Container Throughput Analysis: A Comparative Evaluation of China and Five West Africa Countries Seaport Efficiencies. *International Journal of Engineering Research in Africa*, Vol. 22, pp. 162-173. ISSN: 1663-4144, Doi:10.4028/www.scientific.net/JERA.22.162. Available: https://www.researchgate.net/publication/295812641_Container_Ports_Throughput_Analysis_A_Comparative_Evaluation_of_China_and_Five_West_African_Countries%27_Seaports_Efficiencies Accessed[03/07/2019]
49. Tongzon, J.L. (2001). Efficiency Measurement of Selected Australian and Other International Ports Using DEA. Transportation Research Part A, Vol.35, pp.107-122.
50. United Nations Conference on Trade and Development (2018). *Review of Maritime Transport.* Available at https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf [Accessed 14 June 2019].
51. Van Dyck, G.K. (2015). Assessment of Port Efficiency in West Africa Using DEA. *American Journal of Industrial and Business Management*, Vol.5, pp.208-218. Available at: http://dx.doi.org/10.4236/ajibm.2015.54023 [accessed 31 10 2018].
52. Wanke, P.F., Barbastefano, G.R. and Hijjar, M.F., (2011). Determinants of Efficiency at Major Brazilian Port Terminals. *Transport Reviews*, Vol. 31 (5), pp. 653-677.
53. Wisnicki, B., Chybowski, L. and Czarnecki, M. (2017). Analysis of the Efficiency of Port Container Terminals with the Use of DEA Method or Relative Productivity Evaluation. *Management Systems in Production Engineering*, Vol. 1(25), pp. 9-15. DOI 10.1515/mspe-2017-0001.
54. Yongrok, C. (2011). The Efficiency of Major Ports under Logistics Risk in North East Asia. *Asia-Pacific Journal of Operational Research*, Vol. 28, (1), pp. 111–123. DOI: 10.1142/S0217595911003089.