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SELECTION OF GATEWAY PORT FOR WEST AFRICAN LANDLOCKED COUNTRIES USING DATA ENVELOPMENT ANALYSIS

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Abstract: **Landlocked countries (LLCs) in West Africa have (13) thirteen alternative transit corridors for shipment. The paper selected 6 alternative transit corridor based on its annual throughput with the aim of finding a gateway port for these LLCs using Data Envelopment Analysis (DEA) based on operational efficiency. The DEA model has commonly been used in the port sector. DEA window analysis is used to determine the efficiency of ports and to observe the possibility of changes in the port efficiency over time. Total quay length, terminal area, total quayside cranes, total number yard gantry cranes and total number of reach stacker were employed as the input variable and container throughput as an output variable. The study concluded that that the Port of Tema in Ghana and the port of Abidjan in Ivory Coast were the most efficient West African port under the study even though they showed some inefficiencies but overall it was found out that make good use of the its resources available. On the other hand the Port of Cotonou in Benin was found to be the least efficient port obtaining the lowest average efficiency rating over an eight year period.**

Keywords: **DEA Analysis, Port Efficiency, West-Africa, Window Analysis, West African Landlocked countries (LLCs), Efficiency, Performance.**

1. INTRODUCTION

Port competition worldwide has come about due to containerization and container transportation. The interest in efficiency by port operators [1] port users has increase port competition. With high port efficiency and performance ranked first amongst a list of factors [2] considered in selection of port. West African ports have been noted to be highly congested and inefficient [1] as compared with ports in Europe and Asia.

Out of the 16 West African countries 13 has direct access to the sea while only 3 (Burkina Faso, Mali and Niger) are Landlocked countries. However, to the author's knowledge, no empirical study has been undertaken to determine the relative efficiency of ports in the region. The aim of this paper therefore is to empirically assess the efficiencies of ports in WA utilizing the DEA method in selection of gateway port for West African Landlocked Countries.

Traditionally, the three LLCs have been using neighboring francophone coastal countries as their transit port. The only three LLCs in West Africa are former France colonies. Colonization brought about institution of different languages, currencies and borderlines. Thus, the French had eleven (11) colonies, while Britain and Portugal administered four and one respectively.

The LLCs has thirteen options for alternative transit corridors but that has not been the situation due to variety of factors including the high cost of constructing and maintaining new transit corridors and differences in languages and currencies, which have acted to preserve the predominance of traditional corridors" [3].

Subsequently, Anglophone countries like Ghana and Nigeria have over the years been left out of the transit trade as far as the landlocked hinterland is concerned. However, as time went by, transport and communication networks improved, ECOWAS (Economic Community of West African States) and other regional cooperative efforts were also embarked upon. This made it possible for the LLCs to broaden their sources of supply of marine services. Beside these reasons, the political instability in some parts of the West African sub region has also made it strategically unsafe for the LLCs to continue relying solely on their traditional Francophone transit corridors [18]. This resulted in some of the LLCs formulating deliberate national strategic policies to use other transit corridors in addition to their traditional ones. As a result, transit operators began exploring other corridors, especially Ghana in the late 1980's. Since its inception, the transit traffic through Ghana has been increasing considerably.

2. LITERATURE REVIEW

Data envelopment analysis (DEA) is a non-parametric linear programming based technique for evaluating the relative efficiency of asset of decision making units (DMUs) and was introduced by Charnes, Cooper, and Rhodes [4], large number of research on DEA models has been developed, such as BCC model (Banker, Charnes,& Cooper,[5],FDH model[6], SBM model[7],EBM model [8], RBM model [9] and NEBM[10].As indicated in [11], DEA can be applied to identify sources of inefficiency and efficiencies, rank the DMUs, evaluate management, evaluate the effectiveness of program or policies, create a quantitative basis for reallocating resources, etc. Over the last decade, DEA has gained considerable attention as managerial tool for measuring the performance of DMUs and port performance.

During the last two or three decades many research papers attempting to evaluate port efficiency using the DEA method have been conducted. The research papers can be roughly divided into two groups according to the data analysed. The first group represents studies analysing cross-sectional data, while the second group deals with panel data. Both groups of papers compare the performance of ports in the European countries [12], the Asian countries [15], the USA and Australia [13]. However, as far as the authors know, research works have not included ports in West Africa. In the recent years the DEA method has successfully applied to the analysis of container terminal in seaports.

Application of the DEA technique was in the studies of [6] on the port sector. They recommended cross-section data in evaluating the effectiveness of various ways of organizing port services. Although they introduced multiple outputs such as port throughput and customer satisfaction their work was restricted to the application of the standard DEA methods such as the DEA-CCR model. In addition, their work was limited to the one period of time. They examined 20 seaports and chose the size of the labour force, annual investment per port and the uniformity of facilities and cargo as input variables and the number of containers, the level of service, customer satisfaction and the number of ship calls as output variable.

DEA window analysis was evaluated by [4] to determine the efficiency of 11 container terminals in a period of four years. DEA window analysis enables observation of the changes in terminal efficiencies over time. The data included the total quay length, the number of cranes, labour number, size of storage, all belonging to inputs and cargo throughput as the output. The specific choice of input and output variables is important when using DEA model for critical analysis of efficiency of ports. Undefined variables may lead to misleading conclusions about port efficiency [14]. Input and output variables are supposed to reflect container port production as much as possible [20]. Container throughput are output data which are normally used to analysed port performance and the basis which port is compered. As container port depends on the efficient use of land, labour and capital (equipment), the input data used include the quay length (in meters), the terminal area (in hectares), the number of quayside cranes, the number of yard gantry cranes, and the number of reach stackers used in each port over the period under study.

DEA concerns itself with assessing the efficiency of an individual firm. This firm is the fundamental unit of analysis that, following aggregation, makes up the sample for analysis and is typically defined as the Unit of Assessment or the Decision Making Unit (DMU) [4]. In either case, the terminology refers to the organizational entity responsible for controlling the process of production and for making decisions at various levels that may influence the productive process and, the level of efficiency associated with it. These include daily operational, short-term tactical and long-term strategic decisions. DEA can be employed to measure the rounded efficiency of a firm by comparing it with other standardized units that transform the same group of measurable positive inputs in to the same types of measurable positive outputs. In fact, this consistency of both the inputs and outputs constitutes a fundamental underlying assumption upon which the veracity of DEA efficiency measures is based. In the absence of such an assumption, the relevance of measuring efficiency across any set of DMUs could undoubtedly be called into question.

The basic principle of utilizing DEA is to measure the efficiency level of firms within a given sample [21]. In relation to assessing the validity of the uniformity, it is important that the quality of inputs utilized by the various ports across the sample is similar. The productivity of any entity is simply the absolute measure of outputs/inputs and, therefore the productivity of each terminal is represented by the calculated ratio of 'throughput'.

In the relation to DEA, [19] the relative efficiencies of all units of analysis measured by comparing their productivity. The way in which efficiency is calculated is based on an assumption that production exhibits constant returns-to-scale. [20] In other words, there are no (dis)economies of scale as the level of productive output changes. The DEA model corresponding to this assumption is termed the DEA-CCR model [4]. Apart from the DEA-CCR model, the DEA-BCC model [5] are the two DEA models that are widely studied and applied. The main difference between the set two models is that the former allows for perhaps a more realistic assumption of variable returns-to-scale, in contrast to the constant returns-to-scale assumed in the DEA-CCR model. The DEA-BCC model of the production frontiers that are estimated by applying the respective techniques. The main difference between them lies with the derivation of the projection path from each of the data points that represent the inefficient firms on to the production frontier. This is important since it is the proportionate distance that results from the projection path that impacts directly upon the efficiency estimate derived for a specific inefficient data point.

3. METHODOLOGY

The basic information derived from the above two DEA models, i.e. the DEA-CCR model, the DEA-BCC model is whether or not a firm can improve its performance relative to the set of firms to which it is being compared. A different set of firms is likely to provide different efficiency results because of the possible movement of the production frontier. The following model illustrates how the relative efficiency score of DMU is obtained in DEA, as proposed by [4].

$$Max\ h_k(u,v)\frac{\sum_{r=1}^{s}u_r y_{rk}}{\sum_{i=1}^{m}v_i x_{ik}}\quad for\ all\ k=1,2,\dots,n \qquad 1$$

Subject to

$$\frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}}\quad j=1,2\ \dots.,n \qquad 2$$

$$u_r \geq 0,\ \ r=1,2,\dots.,s \qquad 3$$

$$v_i \geq 0,\ \ i=1,2,\dots.,m \qquad 4$$

Where:

$h_k$is relative efficiency of k-th DMU, y_{rk} is amount of output r produced by DMU *j*, x_{ij} is amount of input i used by DMU *j*, n is the number of DMUs, *m* is the number of inputs, *s* is the number of outputs, u_r is the weight given to output r and v_i is the weight given to input *i.*

The above model is solved *n* times to evaluate the relative efficiency of each DMU. Mathematically, the nonnegative constraints (3) and (4) are not sufficient for the fractional (2) to have a positive value. Due to that it is assumed that all weights for inputs and outputs assign some nonzero value.

Since the efficiency of *k-th* DMU is maximized by solving the expressions (1), (2), (3) and (4) it is obvious that $h_k$will take values from 0 to 1. If the value for $h_k$is equal to 1, then the k-th DMU will be efficient relative to other DMUs; otherwise, the value of $h_k$indicates the inefficiency of *k-th* DMU. The inefficiency of some DMU can be treated as "less efficient DMU" if the value of $h_k$is close to 1.

$Max\ h_k(u,v) = \sum_{r=1}^{s} u_r\, y_r\ for\ all\ k = 12, \ldots, n$ 5

Subject to

$\sum_{i=1}^{m} v_i x_i = 1$ 6

$\sum_{r=1}^{s} u_r v_r - \sum_{i=1}^{m} v_i j_i \leq 0\ \ j = 1,2, \ldots, n$ 7

$u_r \geq \varepsilon,\ \ r = 1,2, \ldots s$ 8

$v_i \geq \varepsilon,\ \ i = 1,2, \ldots . m$ 9

Where:

h_k– Relative efficiency of k-th DMU;

n – number of DMUs that should be compared;

m – Number of input values;

s – Number of output values;

u_r – Weight of the output value r;

v_i– weight of the input value i.

If the value of h_k in the objective function is equal to 1, then *k-th* DMU is relatively efficient. However, if it is less than 1, then DMU *k* is relatively inefficient and the value of h_k shows the percentage by which DMU should decrease its inputs. DMU *k* can be considered fully efficient only, and only if, the values of other DMUs do not provide the evidence that any of its in-puts or outputs could be improved without impairing any other input or output. Looking at expressions (5), (6), (7), (8) and (9) it is obvious that time as a component is not incorporated.

One way of using the DEA method in time series mode is the Window Analysis. This mode is described as; A DMU in each period is a different DMU and the data for use in the analysis is panel data. The performance of a DMU is compared with its performance in other periods of time and with other DMUs in the same period of time. For instance, if n DMUs in N periods of time are considered, then a total of nxN DMUs need to be assessed simultaneously since DMU in year 1 is treated as a different DMU as compared to the same DMU in year 2.

3.1 DEFINITION OF INPUT AND OUPUT VARIABLES AND POPULATION SAMPLE:

Six (6) major ports in West Africa was considered in terms of throughput with ports with annual throughput of over 100,000 TEUs from a population of 12 West African ports. Container throughput trend for the period 2006-2013 will be considered in this study. It helped understand the fluctuation of throughput over time and to know the characteristics of other ports over time.

Port efficiency evaluation using DEA begins from the appropriate choice of inputs and output variables. Total quay length, terminal area, total quayside cranes, total number yard gantry cranes and total number of reach stacker are chosen as input variables while container throughput per year is the output variable [16]. One DMU correspond to one port.

Total quay length is one of the important input of measuring port performance. It determines the type of vessels or size that can call at port at one point in time and also determines the turnaround time of the vessel.

Total number of quayside cranes increases efficiency and flexibility allowing ports to work on more vessels simultaneously therefore helping to reduce ship turnaround time and the speed at which a vessel can be served.

Yard gantry cranes and reach stackers are mainly used in the yard and can be used to assess the number of containers that can be moved or stacked in the yard and the terminal area determines the number of containers that can stacked or allocated at a particular point in time[17].

4. DATA AND ANALYSIS

The study concentrated on operational efficiency to help LLCs make the best decision on port selection using the DEA model. Out of a population of 12 West African ports 6 major ports were selected based on their annual throughput of 100,000TEUs. Most ports in West Africa are usually managed by a concession and are mostly both dedicated berth or terminal and multi-purpose berths. For the purpose of consistency the study analysed the data based on these dedicated terminals. These container terminals are the main terminals handling containerised cargo at the ports. The ports analysed can be found in Table 1 below;

Table 1: Container Throughput for selected ports (2006-2013) (source: [24][25])

Container Throughput(TUEs)									
PORT	**TERMINAL**	2006	2007	2008	2009	2010	2011	2012	2013
Port of Tema	MPS Terminal	425,408	489,147	555,009	525,694	590,147	756,899	824,238	793,312
Port of Abidjan	SETV Terminal	507,100	531,809	652,358	610,185	561,535	546,417	633,917	745,102
Port of Dakar	DP World Terminal	375,876	424,457	347,483	331,076	349,231	369,137	383,903	428,171
Port of Lomé	Bollore Africa Logistics	215,892	237,891	296,109	354,480	339,853	352,695	288,481	346,234
Port of Cotonou	Bollore Africa Logistics	140,500	167,791	193,745	272,820	316,744	334,798	348,190	388,341
Lagos Port Complex	APM Terminals Apapa	587,600	711,100	710,800	710,800	1,128,171	1,413,273	1,623,141	1,010,836

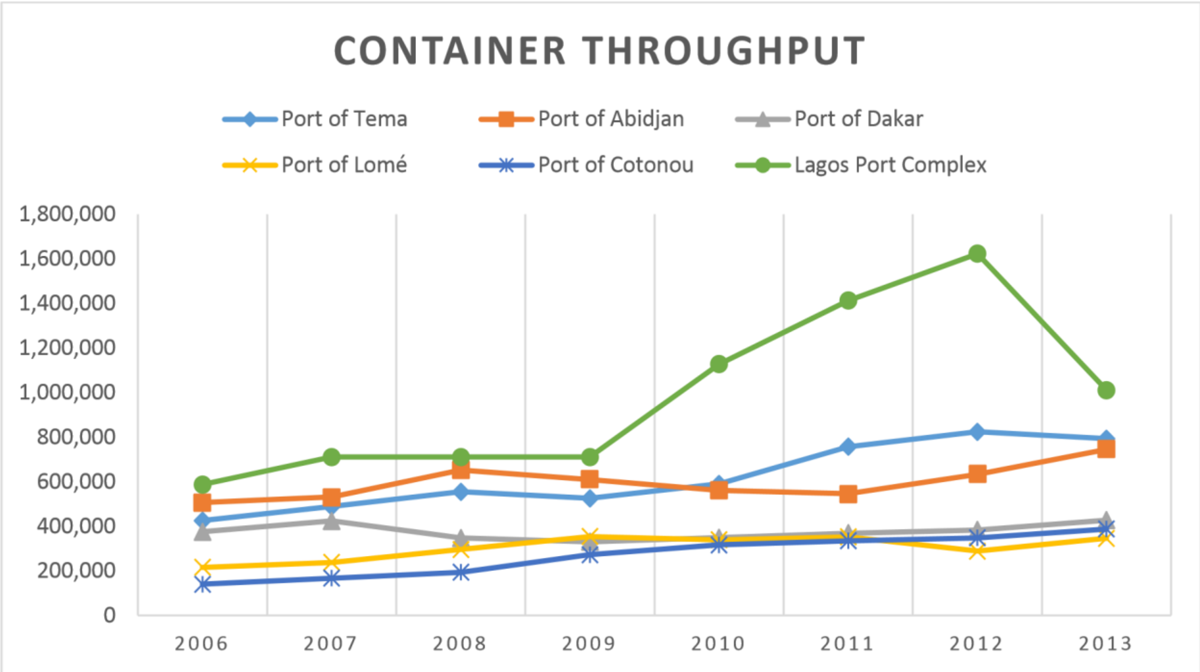

Figure 1: Container Throughput Trend (2006-2013) (source: DEA Solver)

Figure 1 above shows the container throughputs of the selected ports from 2006-2013. It could be seen that Lagos port complex has the highest throughput but there is variation through the years under study. The other ports also have some variation at some point time except the port of Cotonou which has an upward trend since 2006 and 2007.

Selection of port input and output variation are very important given that an undefined variable may lead to misleading assumption about port performance. This variable should reflect on productivity as much as possible. The input data and output data can be seen in table 2 below. The table also show the infrastructure development throughout the years. It could be seen that most of the ports have not had any major change in development throughout the years except the port of Tema and Abidjan. Lagos port complex leads the in terms of infrastructure development and it also a surprise that the port of has no yard gantry cranes.

Table 2: Input and Output variables for various port. (Source: various port authorities)

Ports	Year	Container Throughput	Total Quay Length	Terminal Area	No. of quayside cranes	No. of yard gantry cranes	No. of Reach stackers
Port Of Tema	2006	425,408	574	10	6	4	0
	2007	489,147	574	10	6	4	4
	2008	555,009	574	10	6	4	4
	2009	525,694	574	10	6	4	10
	2010	590,147	574	10	6	4	10
	2011	756,899	574	10	6	4	10
	2012	824,238	574	10	8	13	23
	2013	793,312	574	10	8	13	23
Port Of Abidjan	2006	507100	1000	34	3	16	19
	2007	531,809	1000	34	3	16	19
	2008	652,358	1000	34	3	16	19
	2009	610,185	1000	34	3	16	19
	2010	561,535	1000	34	3	16	19
	2011	546,417	1000	34	3	16	19
	2012	633,917	1000	34	4	16	19
	2013	745,102	1000	34	4	16	19
Port Of Dakar	2006	375,876	660	35	4	8	15
	2007	424,457	660	35	4	8	15
	2008	347,483	660	35	4	8	15
	2009	331,076	660	35	4	8	15
	2010	349,231	660	35	4	10	15
	2011	369,137	660	35	4	10	15
	2012	383,903	660	35	4	10	15
	2013	428,171	660	35	4	10	15
Port of Lomé	2006	215,892	430	12	4	0	19
	2007	237,891	430	12	4	0	19
	2008	296,109	430	12	4	0	19
	2009	354,480	430	12	4	0	19
	2010	339,853	430	12	4	0	19
	2011	352,695	430	12	4	0	19
	2012	288,481	430	12	4	0	19
	2013	346,234	430	12	4	0	19

Port	Year	Container throughput	Total Quay Length	Terminal Area	No. Of Quayside Cranes	No. Of Yard Gantry Cranes	No. of Reach Stackers
Port Of Cotonou	2006	140,500	540	20	4	10	15
	2007	167,791	540	20	4	10	15
	2008	193,745	540	20	4	10	15
	2009	272,820	540	20	4	10	15
	2010	316,744	540	20	4	10	15
	2011	334,798	540	20	4	10	15
	2012	348,190	540	20	4	10	15
	2013	388341	540	20	4	10	15

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Lagos Port Complex	2006	587,600	1005	55	10	12	31
	2007	711,100	1005	55	10	12	31
	2008	947,400	1005	55	10	12	31
	2009	710,800	1005	55	10	12	31
	2010	1,128,171	1005	55	10	12	31
	2011	1,413,273	1005	55	10	12	31
	2012	1,623,141	1005	55	10	12	31
	2013	1,010,836	1005	55	10	12	31

Table 2 above shows the input and output data. Data was collected from World Bank, Port Management Association for West and Central Africa, and from major terminal operators of the port and port authorities. It was processed using the DEA-SOLVER pro 5.

The length of window length was 4 which can found Table 3 below which takes into account for the different changes in efficiency over time.

Table 3: Window analysis results. ((Source: DEA Solver)

	2006	2007	2008	2009	2010	2011	2012	2013	Average	C-Average
Port of Tema	1	0.88	1	0.94					0.95	
		0.88	1	0.89	1				0.94	
			1	0.69	0.77	1			0.86	
				0.69	0.77	1	1		0.86	
					0.77	1	1	0.96	0.93	0.91
Port of Abidjan	0.77	0.81	1	0.93					0.88	
		0.81	1	0.93	0.86				0.9	
			1	0.93	0.86	0.83			0.9	
				1	0.92	0.89	0.86		0.92	
					1	0.97	0.85	1	0.95	0.91
Port of Dakar	0.73	0.82	0.67	0.64					0.71	
		0.79	0.65	0.61	0.65				0.67	
			0.55	0.53	0.55	0.59			0.55	
				0.48	0.51	0.54	0.56		0.52	
					0.51	0.54	0.55	0.62	0.55	0.6
Port of Lomé	0.6	0.67	0.83	1					0.77	
		0.67	0.83	1	0.95				0.86	
			0.83	1	0.95	0.99			0.94	
				1	0.95	0.99	0.81		0.94	
					0.96	1	0.81	0.98	0.94	0.89
Port of Cotonou	0.31	0.37	0.42	0.6					0.42	
		0.33	0.39	0.55	0.63				0.48	
			0.32	0.46	0.53	0.56			0.47	
				0.41	0.47	0.5	0.43		0.45	
					0.47	0.5	0.43	0.48	0.47	0.46
Lagos Port Complex (Apapa)	0.61	0.74	0.99	0.74					0.77	
		0.63	0.83	0.63	1				0.77	
continued										
			0.67	0.5	0.79	1			0.74	
				0.43	0.69	0.87	1		0.75	
					0.69	0.87	1	0.62	0.79	0.76

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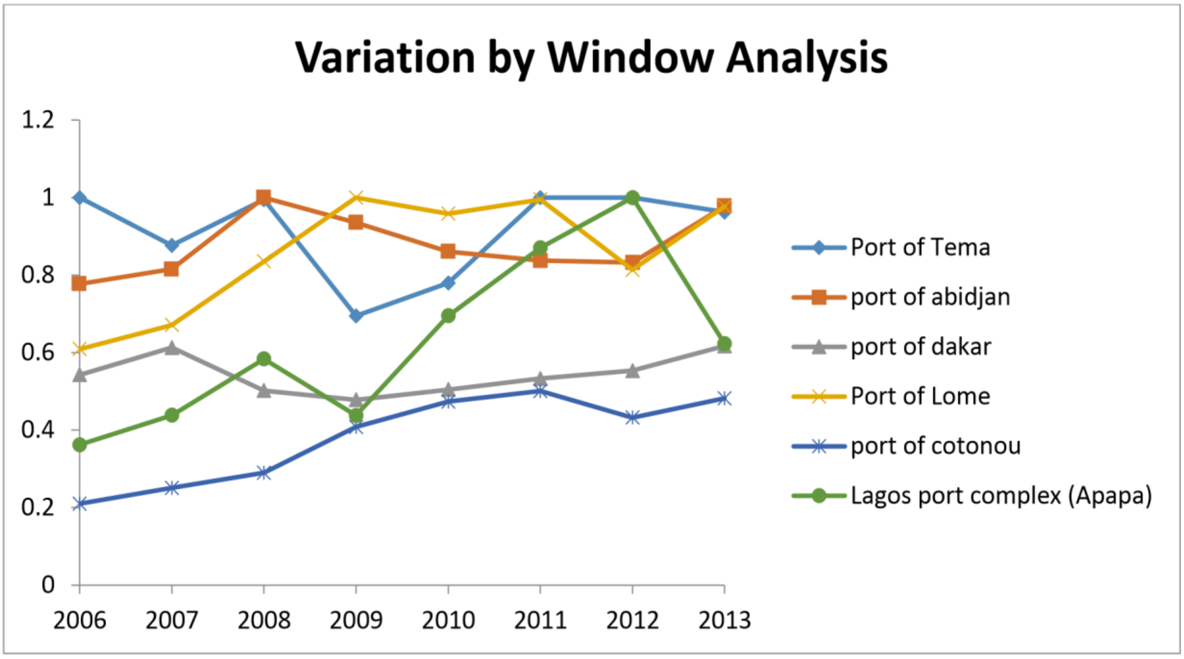

Figure 2: Port efficiency variation by window analysis. (Source: DEA Solver)

Table 4: Port efficiency ranking for selected ports. (Source: DEA Solver)

Port	Average Scores	Rank
Port Of Tema	91%	1
Port Of Abidjan	91%	1
Port Of Lomé	89%	3
Port Of Lagos Complex (Apapa)	76%	4
Port Of Dakar	60%	5
Port Of Cotonou	46%	6

Table 4 shows the average scores and rank of the ports from 2006 – 2013.

From table 3 we have a four window table. The length of the window is defined as four. Four windows are represented as four rows per one port. Each port is represented as a different DMU at each of the four successive years.

Looking at the low percentages of the port of Cotonou in table 3 it can be concluded that it is the most inefficient one in four windows. It is clear that there exists substantial waste in production from the average of 46% In term of port size the port of Tema and Cotonou are similar but the port of Cotonou achieved significantly lower output to the port of Tema.

The port of Tema and Abidjan are the most efficient port a mong the 6 ports with an average score of 91%. It is impressive that both ports scored at one point in time scored 100% efficiency in their operation. This may be due to their standard of infrastructure. Tema port increased their reach stackers from 0 to 23 and also increased their yard cranes from 4 to13 in 2013. Abidjan also increased their yard cranes and with advantage of having the deepest draft of 15meters among the lot.

However, out of the eight years under review the port of Tema and the port of Abidjan achieved efficiency in four, the lowest being 2009 and 2006 respectively. For port of Tema it was due to the world financial crisis on trade and for the port of Abidjan it was due the political unrest during that time, they both registered 69% and 77% respectively.

In 2006 and 2007 the port of Lomé registered a low efficiency but there was an upward rise between 2009 and 20011 but registered a low score in 2012 but shot up in 2013. The port of Lomé is the 3rd ranked port in the study with an average score of 89%.

With highest throughput of among the 6 major ports, the port of Lagos registered only 76% and ranked 4th. Lagos port complex having a good number of inputs be ranked 4th shows that bigger is not always better. It also indicate that infrastructure is underutilised.

On the average, the port of Dakar is said to have registered an average performance throughout the period under study. In 2009 it registered its lowest efficiency in 48% which has been the trend for most of the ports. It however managed a high efficiency score of 2007, averaging 60%.

5. CONCLUSION

DEA is a commonly tool used in measuring port performance and terminal efficiency. It requires multiple inputs and output with accurate data and comparable DMUs. Operational efficiency of 6 ports majors ports based on annual container throughput of 100,000TUEs looking to become the gateway port for West African Landlocked countries are analysed with the Port of Tema and the Port of Abidjan scoring an average score of 91%. On the other extreme, the study finds that the Port of Cotonou is least efficient and exhibited substantial waste in production throughout the period under study.

Improving efficiency of ports in West Africa should be the primary objective of port authorities. In terms of quantity and area size, Lagos port complex Apapa is ahead of other ports in total quay side, terminal area, number of quayside cranes and reach stacker. It is therefore a surprised that their efficiency ranks the port only 4th. It is of the assumption there are too many input for a certain level of output or infrastructure may not be at the right area or place. The author is optimistic that in the near future efficiency rank of the port will change for the better if resources are managed properly.

There has not been any major infrastructure development between 2006 and 2013 for the Ports of Cotonou, Lomé and Lagos port complex this reflected in their efficiency performance throughout the years under study. Ports that have had major improvement in infrastructure had a good efficiency performance throughout the years under study. The port of Tema increased its number of yard gantry cranes from 6 to 8, number of quayside cranes was also increased from 6 to 8 and reach stackers increased from 0 to 23 it is therefore not a surprised that it ranked 1st in its performance. Port of Abidjan which also rank 1st also increased its quayside cranes.

It is therefore of the view that if there is improvement of port infrastructure there could be a different outcome of efficiency ranking among west African port. The measure could significantly affect the outcome of the final results of the study perhaps Lagos port complex could be ranked 1st.

Furthermore, as it has been stated earlier that ports in the region have limitations in accommodating larger vessels, which would enable the benefit of economies of scale for both shipping lines and shippers. This fact represents a challenge for these ports in the future if account is taken of the year by year increasing traffic. With shipbuilder building bigger ship the author predicting that in five to ten years container vessels requiring up to 14m draught will be calling at West African ports. Since there are multiple ports along the West African coast, improving port connectivity for shipping lines could be enhanced by the affirmation of one port as a gateway port for West African Landlocked countries.

The authors believe that with absence data constraint the paper would have had a different for the result. Data for 2014 and 2015 input and output variable could have changed the outcome of the research but unfortunately at the time writing this paper they were not readily available. Furthermore, with ongoing port projects by West African port authority it is believe that port congestion and improvement of performance efficiency will be attained. The Port of Lomé is constructing a $640 million berth in Togo with a quay which will double the docking capacity and accommodate vessels of more than 7000 TEU capacity [22]. The Ghana Ports and Harbours Authority (GPHA) has secured $1.5 billion for expansion of the Port of Tema. The aim of the project is to create the largest cargo port in West Africa with a capacity of 3.5 million TEU per annum once complete in 2018 [23]. Similar port development projects can be found in other West African. It’s of the view that these ports projects can contribute to the economy of the region and also these ports can one day compete with ports in Europe and Asia.

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