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Determination of the Efficiency of Port Performance and Productivity Based on Data Envelopment Analysis in the West Africa Sub-region

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Abstract

Background: Ports are one of the assets of every country and one way to achieve efficiency is by maximizing productivity amid limited resources. Despite the increase in the number of studies on the efficiency of container terminals, their focus has been channeled on advanced markets. Researchers conduct limited studies on container terminals in developing countries such as those of the West African region, which are located in a critical geographic place in the international maritime route between these areas and the World. Information on their potential for development relative to other terminals worldwide is therefore not readily available hence, this study seeks to provide answers to critical productivity indicators of ports in the West Africa sub-region. **Methods :** We evaluate the technical efficiency of the 5 major container terminals in the West African region. The Data Envelopment Analysis (DEA) approach is used to measure technical efficiency and slack variable analysis which identifies potential areas of improvement for inefficient terminals. Moreover, DEA can handle multiple inputs and outputs, which makes it applicable to the port analysis. **Findings:** The results indicate that the Tema port is the most efficient port among the sample, with an average efficiency of 100% in the nine years and the Port of Cotonou is the least efficient with an average efficiency of 44% and exhibits substantial waste in production throughout the nine-year analysis. **Novelty:** This is the first time that the current data from 2010-2018 has been used to determine port efficiency and the efficiency scores are necessary indicators for terminal managers to adopt and sustain all the necessary alignments to structures and strategies.

Keywords: Data envelopment analysis; productivity improvement; efficiency; port management; West Africa

1 Introduction

Port terminals serve as a significant link between ports and the overall global logistics chain, and as such, the importance of operating an efficient port cannot be overemphasized. It is estimated that about 108 trillion tonne-kilometers were transported globally, with over 70% routed by sea, with a projected spike in a few years to come[(1)]. This has heightened the overall competition among container terminals, creating the urgency for port authorities to enhance port efficiency, ensuring that port services meet the international competition standards that support trade-oriented economic development[(2)]. This has made the efficiency of ports terminal operations strategic for national port authorities due to the growing competition among ports around the world to attain regional/global hub[(3)]. The concept of port efficiency is multi-dimensional and encompasses but is not limited to the maximization of production output given limited resources. This is achieved using the comparative model by which port operations and monitoring services are compared for overall efficiency and to determine their performances relative to established benchmarks[(2,4,5)]. In addition, the comparative model reveals a correlation between ports and the overall trade chain, making port efficiency an important add-up to a nation's regional and international competitiveness[(6)]. Based on the outcome of routine port efficiency measurement, policymakers adopt any necessary alignments to structures and strategies[(5)]. For the most part, the comparative model or "benchmarking" aims to identify the most critical performance measures for each part of a business operation; to compare internal performance levels with those of the leading competitors; to assess areas where the company has comparative advantages and disadvantages; to implement programs to close the performance gap between internal operations and the top competitors[(2)].

Traditionally, the indicators used to measure port efficiency include berth occupancy, revenue per ton of cargo, turnaround time, capital expenditure per ton of cargo[(5)]. In recent years, the increase in competition among container terminals has attracted researchers to probe into how these terminals can decrease their turnaround time of vessels and increase their throughput to maximize ports' efficiency[(7)]. Many researchers have used parametric and non-parametric methods to measure ports' capacity and efficiency on the global and regional levels. These techniques include original least squares (OLS), corrected original least squares (COLS), data envelopment analysis (DEA), and stochastic frontier analysis (SFA)[(8,9)]. These methodologies have their pros and cons. The SFA is a parametric method for large-scale benchmarks that can predict an efficient frontier production using time series data. However, it is subject to measurement error, which may result in erroneous estimates due to issues with the specification of the production technology[(8,10)]. By contrast, the DEA is the most frequently used non-parametric method. It is not dependent on a priori weighting of performance measures and provides quantitative insights into operational efficiency improvement. Additionally, DEA has proved to be essential in benchmarking; it is used to determine the relative efficiency of Decision-Making Units (DMUs). DEA is also used to measure port performance and productivity[(2,8,11,12)].

DEA approach has been applied across different research domains such as environmental, banking and finance, health sector, educational sector, transport, airline, tourism, and many more because it is popular and robust[(13–19)]. The use of DEA for benchmarking in ports is wide globally, particularly in developed economies[(2,6,8,20–22)]. Bassan (2007) proposed a cost and input parameters-dependent method for evaluating the port terminal operation and capacity analysis that enhances decision-making. Depending on the decision makers' strategy, the weighted service level is determined. On the other hand, his input-based methodology relies on the availability of historical data on cost and input parameters, which is hard to acquire in most developing countries, and at the same time, the accuracy of such information is hard to determine[(23)]. The African counterpart ports are not left out due to the urgency of ports to attain regional/global hubs due to the growing rate of competition among ports[(3)]. Manase and Ngangaji (2019) assess the efficiency and operational scale of the dedicated container terminals in major East African ports using integrated methods. They used three ways to analyze the ports' efficiencies: Ratio analysis, the econometric frontier (also SFA), and DEA. The conclusion indicates that Dar Es Salaam and Mombasa Ports should collaborate to increase demand for containers currently handled by the Durban port as transshipment[(24)]. Van Dyck (2015) also used DEA to investigate the efficiency of six major West African ports. His findings indicate that significant deficits in production transpired in the majority of ports in 2009, probably due to the global financial crisis and subsequent reduction in output. Other inefficiencies were identified, including a smaller customer base (and thus a low production) in comparison to the inputs used in the port's operations[(25)]. Comparably, West African ports can operate at a reasonable level of efficiency given the available resources, as evidenced by the fact that four out of six ports achieved an average efficiency score of 76 percent or higher during the study period[(26)]. One way to sustain this high level of operational efficiency by these ports is by routine measurement ports efficiencies and adopting all the necessary alignments to structures and strategies[(5)]. Due to minimal resources and expertise in developing countries, these ports surely rely on the research findings across different fields of studies and the developed countries of the world.

The ultimate goal of this study is to measure the operational efficacies of the five most prominent ports in the West African sub-region (Figure 1). The results will help propose solutions for better performance and develop efficient plans for managing the ports. The adopted method is the DEA approach. The paper has four sections: section 1 covers the general introduction and relevant literature review; in section 2, the DEA methodology used. The methodology covers the main equations and the implementation of the method. We presented, analyzed, and discussed the results of the study in section 3. Section 4 is the conclusions of this study.

Fig 1. Map extract showing the location of thefive ports marked by anchor symbols. The insert (top left corner) is the map ofAfrica showing the study region in a black rectangle.

2 Materials and Methods

2.1 The data envelopment analysis (DEA)

The Data Envelopment Analysis (DEA) adopted for this study has a long history. It as a model developed for estimating technical efficiencies without specifying subjective weights for each input or output variable or modifying all variables to economically comparable values [27]. The non-parametric method is based on two critical sets of multiple variables, referred to as the inputs and outputs [28]. DEA is a data-driven approach for evaluating the performance of collected entities known as DMUs that convert inputs to outputs. The DEA presupposes the possibility of linear combinations of the observed input-output bundles [26]. DEA is a critical decision tool for assessing the performance of decision-making units and has been applied in a variety of sectors for management control and organizational evaluation [13–19,29]. DEA performance indicators do not assign weights; this process is by mathematical programs associated with the analyzed points to determine the best possible efficiency score [27].

The model chosen for this study is the input-oriented DEA, also known as DEA-CCR. The CCR model seeks to maximize a decision-making unit's efficiency value by selecting the optimal weights for each input and output factor [28]. By minimizing efficiency, the linear programming problem for DEA's input-oriented, constant returns to scale version is presented (E) for $w_I, w_2, \ldots, w_N$, E_n,

subject to:

$$\sum_{j=1}^{N} w_j x_{ij} - E_n y_{in} \geq 0; \quad i = 1, \ldots, I \tag{1}$$

$$\sum_{j=1}^{N} w_j x_{ij} - E_n x_{in} \leq 0; \quad k = 1, \ldots, K \tag{2}$$

$$w_j \geq 0; \quad j = 1, \ldots, N \tag{3}$$

Where N organizations generate different outputs y for I = 1,.., I while utilizing K distinct inputs x for k = 1,..., K. The w_j are weights spread across all N organizations, and E_n is the nth organization's efficiency score. The linear program finds the convex combination of N data points that can provide at least the observation n output while using at most E_n times the observation n inputs. We solved for each of the N organizations to obtain a complete set of efficiency scores.

2.2 Data and variable selection

We examined the container terminal efficiencies through their basic function, that is, the transfer of the containers from sea to inland and back to the sea. To transport the containers within the terminal itself, and from ship to berth, facilities require handling equipment to load and unload the containers, quays for ships to berth, and an area to store containers. The input and output variables must show the actual objectives and processes of the container terminal production as much as possible[30]. The input/output variables include most of the main physical characteristics of container terminal operations, with regards to the availability and reliability of data on technical efficiency, excluding price and cost.

It was noted by[31] that the production of container terminals depends on the efficient use of labor, land, and equipment. The measurement of terminal production, therefore, is a means of quantifying efficiency in the use of these three. Experts meeting about assessing port efficiency at UNCTAD AD HOC, Geneva, on the 12th December 2012, concluded that port efficiency measurements need to take into consideration multiple types of input (e.g. land, labor, and capital). Given the characteristics of container port production, the terminal area, quay length, and draft are the most appropriate factors for the 'land' factor input, and the amount of quay crane and yard equipment is the most suitable factors for the 'equipment' input factors and used by most previous studies[25,31,32]. The labor data is very difficult to collect because it is often restricted, not only because it is regarded as confidential commercially but also because, in some instances, it can be politically sensitive.

Several authors, like[33–35], claim that spite the difficulties in obtaining reliable direct data and information on labor input, this variable should be exempted from the efficiency evaluation. The 'labor' factor in this study is therefore not taken into consideration due to the lack of availability of data, which is typical of most efficiency measurement studies. The selected variables in this study consist of four input variables and one output variable. The input variables are the quay length in meters, the number of quay cranes, the terminal area, and the number of the berth. The output variable is the container throughput, which is the total number of containers loaded and unloaded in twenty-foot equivalent units (TEUs). The container throughput is undoubtedly the most important and widely accepted indicator of container port output and almost all previous studies have treated it as an output variable[11]. Another consideration is that container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a port[36].

The data used was mostly obtained from the United Nations Conference on Trade and Development data bank (UNCTADstat), terminal websites, and the annual reports of ports authorities, the data collected as input and output variables are presented in Table 1.

The five selected ports used for this study (see Figure 1) are Cotonou (Benin), Abidjan (Cote d'Ivoire), Tema Port (Ghana), Lagos Port Complex (Nigeria), and Lomé Port (Togo) between the years of 2010-2018. We carried out the ports selection based on throughput discrimination, i.e., ports with an annual throughput of over 100,000 TEUs, to maintain consistency in comparing the data collected. There are other ports in the sub-region that have lower TEU's which did not fit into our data selection criteria, hence the selection of the 5 ports for this study. Again, the selected ports are the main container terminals for handling containerized cargo. Figure 2 shows the variations of container throughput for the study period 2010-2018. The Lagos port has the highest throughput. All the ports reflected throughput fluctuations, with Lagos port indicating dominance except for Cotonou port, which has consistently increased since 2010. Table 1 shows the summary statistics of inputs and output data. We used a single output, the annual container throughput measured in TEU, obtained from four inputs: number of cranes, terminal area, number of berths, and quay length.

3 Results and Discussion

The results of solving the DEA problem are broken down and shown in Appendices 1a-1e for convenience instead of presenting it in a single long table. The slack movement columns represent the outputs and the inputs of the model. It also shows the extent to which ports would need to reduce inputs in equal proportions to reach the production frontier/efficiency frontier, as shown in Figure 3. For example, Cotonou and Lomé ports must undergo mandatory slack moment by input reduction in equal proportions (also radial movement) and could further reduce without reducing output to arrive at the efficiency frontier.

Table 1. Ports inputs and output data (container throughput) used to carry out the analysis of the study

Ports	Years	Container throughput (teu)	Quay length(m)	Terminal area (ha)	Number of cranes	Number of berths
Cotonou port	2010	316700	600	48	12	5
	2011	334800	600	48	12	5
	2012	348200	600	48	12	5
	2013	348200	600	48	12	5
	2014	348200	600	48	12	5
	2015	348200	600	48	12	5
	2016	348200	600	48	12	5
	2017	333000	600	48	12	5
	2018	333000	600	48	12	5
Abidjan port	2010	530000	960	27	24	3
	2011	546000	960	27	24	3
	2012	633900	960	27	24	3
	2013	633900	960	27	24	3
	2014	600000	960	27	24	3
	2015	625000	960	27	24	3
	2016	705000	960	27	24	3
	2017	907600	960	27	24	3
	2018	907000	960	27	24	3
Tema port	2010	643100	1400	64.2	21	27
	2011	813900	1400	64.2	21	27
	2012	881200	1400	64.2	21	27
	2013	900000	1400	64.2	21	27
	2014	890000	1400	64.2	21	27
	2015	900000	1400	64.2	21	27
	2016	900000	1400	64.2	21	27
	2017	1009400	1400	64.2	21	27
	2018	1009400	1400	64.2	21	27
Lagos port	2010	1232000	950	55	20	10
	2011	1510900	950	55	20	10
	2012	1723000	950	55	20	10
	2013	1580000	950	55	20	10
	2014	1700000	950	55	20	10
	2015	1400000	950	55	20	10
	2016	1437000	950	55	20	10
	2017	1210000	950	55	20	10
	2018	1210000	950	55	20	10
Lomé port	2010	339900	1050	59	7	9
	2011	352700	1050	59	7	9
	2012	288500	1050	59	7	9
	2013	311500	1050	59	7	9
	2014	380798	1050	59	7	9
	2015	905700	1050	59	7	9
	2016	821639	1050	59	7	9
	2017	1193841	1050	59	7	9
	2018	1193800	1050	59	7	9

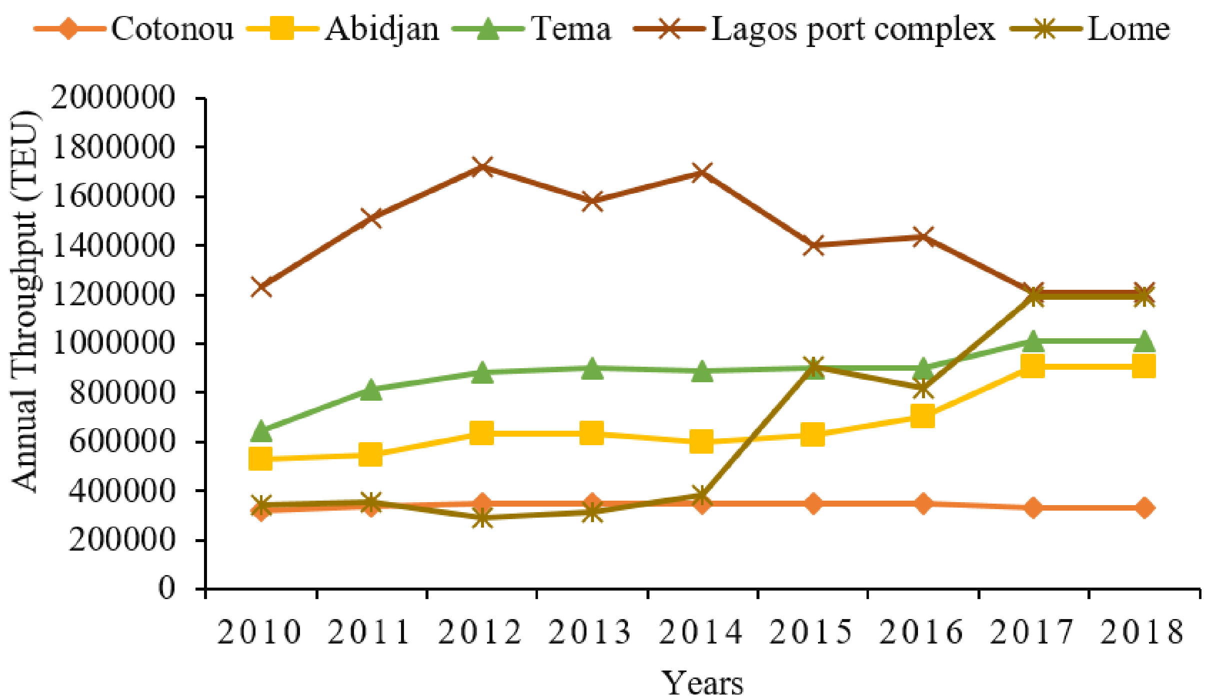

Fig 2. Container throughput for 2010-2018 with the variations for the five ports shown in the legend

The movements presented by reductions and increases to attain efficiency frontier called 'slack moments' in the DEA parlance. The first and second columns (Appendices 1a-1e) show the years 2010-2018 and the variables for the analysis. The original values of the variables' output and inputs ('original values') are in the third column. The fourth column of the table depicts the radial movement required for an ineffective DMU to reach the frontier ('radial movement'). The fifth column represents the extra movement needed for a DMU placed on a section of the frontier that runs parallel to the axis to become efficient ('slack movement'). The values of the variables that enable the DMU to be efficient ('projected values') are listed in column six; these projected values account for both radial and slack movements.

In the year 2010 example (Appendix 1a), the Cotonou port has a throughput of 316700.000 with 600.000 quay length, 48.000 terminal area, 5.000 cranes, and 12.000 berths. However, Cotonou port could 'produce' the same quantity of output with fewer inputs: 274.817 quay length instead of 600.000; 14.324 terminal area instead of 48.000; 2.498 cranes instead of 5.000 and 5.996 berths instead of 12.000 (see the 'projected value' row). Inputs 3 and 4 are decreased by 50% of their original values: (- 2.502 / 5) x 100 for input 3 and (- 6.004 / 12) x100 for input 4. Inputs 1 and 2 have slightly different cases. To become more productive, it must decline not only by 50% (-300.200 from the 'radial movement' column) but also by an additional 24.983 (from the 'slack movement' column) for input 1 and by an additional 24.016 (from the 'radial movement' column) and 9.660 (from the 'slack movement' column) for input 2. Overall, Cotonou port has to decrease its first input by -325.183 (-300.200 - 24.983) to become efficient. This represents 54 % [(- 325.183 / 600) x 100] and second input by -33.676 [(-24.016) + 9.660] which represents 70% [(- 33.676 /48) x 100]. The Tema Port (Appendix 1c), the most efficient port, on the other hand, has a technical efficiency score of 100% throughout the nine-year analysis. This shows that the Tema port is well-managed and does not need to improve its technical efficiency. The 'original value' row contains the original values of the port's variables: the Tema port with 643100.000 throughputs in 2010, with 1400.000 quay length, 25.100 terminal area, 27.000 cranes, and 21.000 berths. These values are equal to the projected ones (technical efficiency of 100%). As Tema port is technically efficient, it acts as its peer.

Table 2 shows the efficiency scores(column 3) of all ports throughout the years of analysis. Based on the technical efficiency, the port with the values of 1.000 is considered efficient, and the values less than 1.000 are inefficient and need improvement in terms of input values. The analysis depicts that Tema and Abidjan ports achieve efficiency throughout the nine-year study. Lagos port complex and Lomé port in Appendix 1d and 1e achieved total efficiency seven years and four years respectively out of the nine years of the analysis compared to Cotonou port that never achieved total efficiency. This is because of the inputs

Table 2. Efficiency summary, peers, lambda weights, and peer counts from the year 2010-2018

Ports	Year	Efficiency	Peer listing	Lambda weight	Peer count	Total peer count
Cotonou	2010	0.5	Lagos, Abidjan	0.233, 0.056	0	
	2011	0.437	Lagos, Abidjan	0.204, 0.049	0	
	2012	0.398	Lagos, Abidjan	0.186, 0.044	0	
	2013	0.431	Lagos, Abidjan	0.201, 0.048	0	
	2014	0.405	Lagos, Abidjan	0.189, 0.045	0	
	2015	0.482	Lagos, Abidjan	5.781, 0.054	0	
	2016	0.433	Lomé, Abidjan	0.237, 0.012	0	
	2017	0.433	Lomé, Abidjan	0.237, 0.012	0	
	2018	0.475	Lomé, Lagos, Abidjan	0.039, 0.179, 0.077	0	0.000
Abidjan	2010	1.000	Abidjan	1.000	1	
	2011	1.000	Abidjan	1.000	1	
	2012	1.000	Abidjan	1.000	1	
	2013	1.000	Abidjan	1.000	1	
	2014	1.000	Abidjan	1.000	1	
	2015	1.000	Abidjan	1.000	1	
	2016	1.000	Abidjan	1.000	1	
	2017	1.000	Abidjan	1.000	1	
	2018	1.000	Abidjan	1.000	1	9.000
Tema	2010	1.000	Tema	1.000	0	
	2011	1.000	Tema	1.000	0	
	2012	1.000	Tema	1.000	0	
	2013	1.000	Tema	1.000	0	
	2014	1.000	Tema	1.000	0	
	2015	1.000	Tema	1.000	0	
	2016	1.000	Tema	1.000	0	
	2017	1.000	Tema	1.000	0	
	2018	1.000	Tema	1.000	0	0.000
Lagos	2010	1.000	Lagos	1.000	2	
	2011	1.000	Lagos	1.000	2	
	2012	1.000	Lagos	1.000	2	
	2013	1.000	Lagos	1.000	2	
	2014	1.000	Lagos	1.000	2	
	2015	1.000	Lagos	1.000	1	
	2016	0.632	Lomé	0.572	0	
	2017	0.632	Lomé	0.572	0	
	2018	1.000	Lagos	1.000	1	12.000
Lomé	2010	0.788	Lagos	0.276	0	
	2011	0.667	Lagos	0.233	0	
	2012	0.478	Lagos	0.167	0	
	2013	0.563	Lagos	0.197	0	
	2014	0.640	Lagos	0.224	0	
	2015	1.000	Lomé	1.000	0	
	2016	1.000	Lomé	1.000	2	
	2017	1.000	Lomé	1.000	2	
	2018	1.000	Lomé	1.000	1	5.000

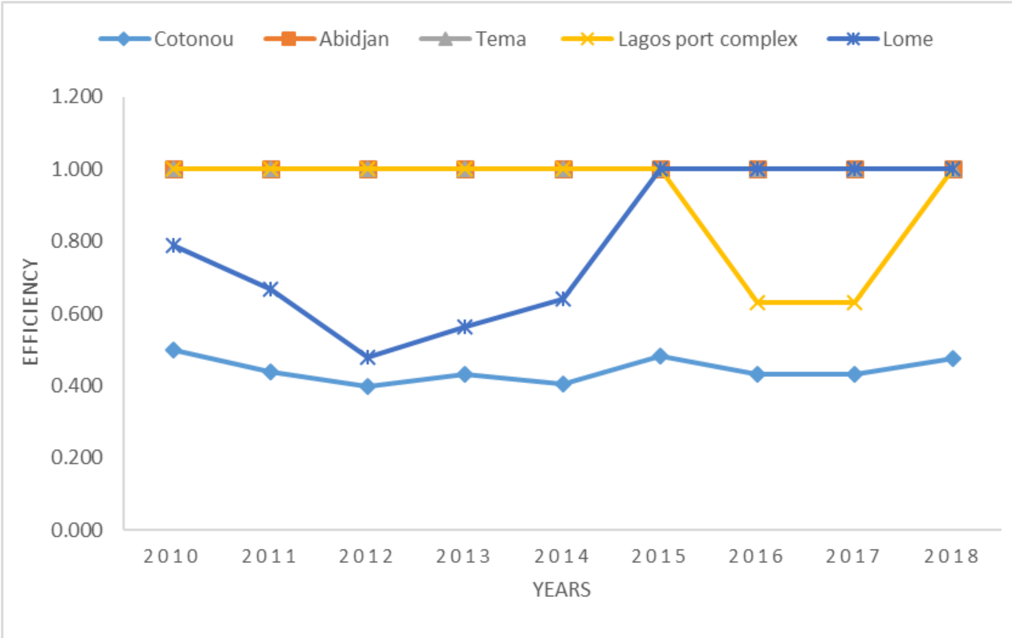

Fig 3. Theplots of input-based orientation showing the input efficiencies for the year2019 based on the actual input values and the expected values to achieveefficiency.

and output values that we considered as the basis of the study of this model. The Cotonou port achieved a 'technical' efficiency score of 50% in 2010, which is halfway down the maximum efficiency mark. The port can improve operations by saving 50% of inputs. The Cotonou port has to analyze the practices of the Lagos port complex and the Abidjan port identified as its peers in column 4 to improve its efficiency (per listing). Each peer is determined by a number with an associated weight ('lambda weight') in column 5, representing the relative importance of the peers. Ideally, the Cotonou port should analyze best practices from a composite port formed by 23% of the Lagos port complex and 6% of Abidjan port (lambda weights); as such, a 'virtual' port does not exist. The peer count in column 6 shows the yearly number of times a port is referenced by inefficient ports to improve. For a port to be a peer (or a benchmark), a port must have a technical efficiency of 100%, as observed for the Lagos port complex and Abidjan port. Cotonou port should concentrate its best practice analysis on the peer associated with the highest lambda value (Lagos port complex). However, it is far more likely that Lagos port is truly efficient because it was a peer twelve times to other ports in the analysis, Abidjan port and Lomé port appear nine and five times, respectively, as presented in column 7. There could be scope for these peered ports to improve their efficiencies even though they receive efficiency scores of 100% at some point in the analysis.

Table 3. Summary of Technical Efficiency average 2010-2018

Ports Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Cotonou port	0.500	0.437	0.398	0.431	0.405	0.482	0.433	0.433	0.475	44%
Abidjan port	1	1	1	1	1	1	1	1	1	100%
Tema port	1	1	1	1	1	1	1	1	1	100%
Lagos port	1	1	1	1	1	1	0.632	0.632	1	92%
Lomé port	0.788	0.667	0.478	0.563	0.64	1	1	1	1	79%
Mean	0.858	0.821	0.775	0.799	0.809	0.896	0.813	0.813	0.895	83%

In Table 3, Tema and Abidjan ports are the most efficient ports in West Africa sub-region, as shown in their products throughout the investigation. They show an average efficiency score of 100% respectively for the entire analysis period. Both ports achieved efficiency in the nine years of study. Lagos Port Complex, located in Nigeria, Africa's largest economy, is the largest port in size and throughput among the ports under study. The port achieves an average efficiency score of 92% from the analysis and exhibits slight fluctuations over time, as with its throughput. Lagos Port Complex achieved its lowest score in 2016 and 2017. The port, however, achieves total efficiency for seven years (i.e., 2010-2015 and 2018) out of the nine years of study. Lomé port achieves relatively higher efficiency scores, exhibits slight fluctuations over time, and achieved total efficiency from 2015-2018. The Ports of Lomé achieves an average efficiency score of 79%. Cotonou port being the least efficient port, achieving an average efficiency score of 44%.Table 4presents the efficiency ranking of the five ports' understudy ranking from Tema port, Abidjan port, Lagos port complex, Lomé port, and Cotonou port (in descending order).

Table 4. Presents the efficiency ranking

Ports	Ranking
Tema port	1
Abidjan port	2
Lagos port complex	3
Lomé port	4
Cotonou port	5

Figure 4 shows the efficiencies variations of the various ports for the study period 2010-2018. The Tema and Abidjan ports lie on 1 that represent 100% through the nine-year analysis. Lagos and Lomé ports show efficiency fluctuations due to slacks in their inputs at some point, whiles the Cotonou port lags below with a 0.600, which shows its inefficiency. The above results also indicate that given the same input resources at any given period, Tema port and Abidjan are the most likely ports to utilize them optimally to produce a corresponding optimal return on investment (ROI). The main goal of a comparative model is for benchmarking, to identify key performance measures for each function of a business operation, and to compare to the performance levels of your leading competitors. This will aid in identifying areas of comparative advantages and disadvantages to implement programs to close a performance gap between internal operations and the top competitors [2]. From this standpoint, Tema port, Abidjan port, and to a large extent, the Lagos ports are the leading ports in the West Africa sub-region. The other ports must look to them in terms of their internal management, operations, and policy implementation to optimize their ROI.

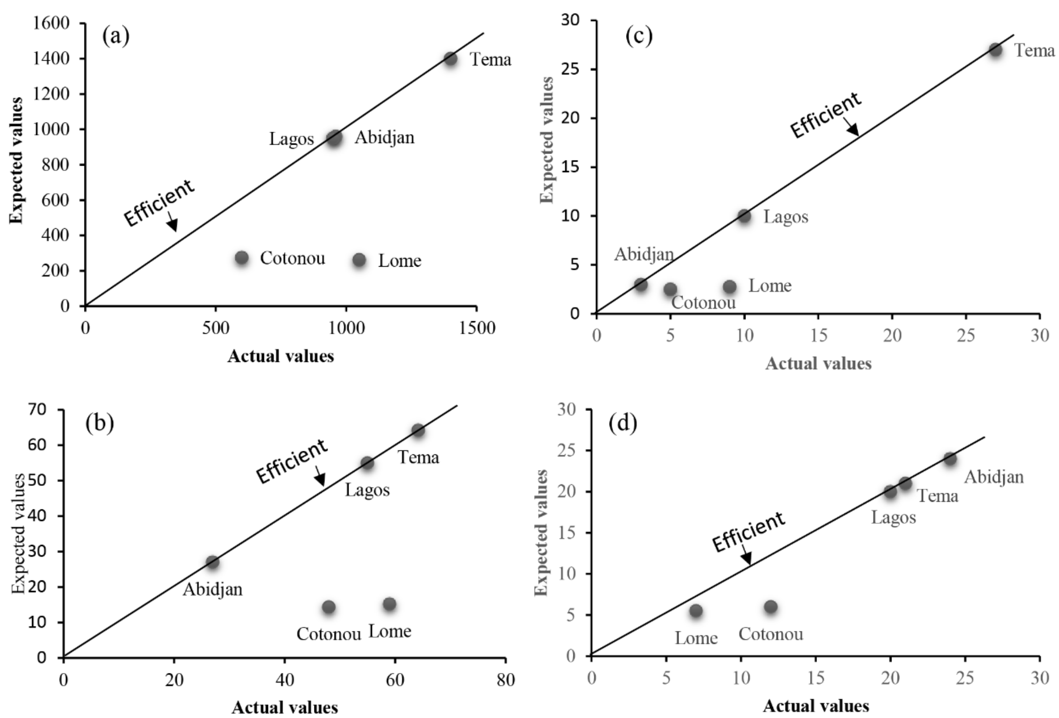

Fig 4. The graphical representation of the technical efficiency variations of the various ports for the study period 2010-2018

4 Conclusion

This study is an attempt to provide a satisfactory understanding of the operational efficiency of container terminals in the West African sub-region and to add to the body of literature available in such studies in this region. The DEA-CCR input-orientation model was used to analyze 5 container terminals from 5 countries in the region. Due to minimal resources and expertise in developing countries which may limit routine data collection and processing, ports management are likely to turn to the research findings across different fields of studies and the developed countries of the world. The efficiency score is a necessary precursor to adopting and sustaining all the necessary alignments to structures and strategies[5].

The results of our study of operational efficiency reveal the following conclusions. The comparison of the efficiency scores of the 5 ports in the region reveals that 3 (Tema, Abidjan, and Lagos) are efficient; the rest of the terminals are inefficient. Cotonou shows the lowest level of efficiency with an average score of 44%. Also, the results of this study reveal that the indicators of production scale and terminal size are not the main factors of efficiency or inefficiency, as Tema port with medium to a low scale of production and size is more efficient than larger ports like Lagos port complex.

The findings recommend that any strategies and plans for ongoing extension and improvements should begin with the right demand forecast and information sharing between port authorities and carriers and shippers. The seaport authorities should adopt policies to encourage shipping lines to load/unload in their seaports, for example by ensuring seaport security, decreasing seaport fees, and improving service performance.

It is also essential that the port authority should conduct yearly comprehensive efficiency evaluations. This will not only support the management of the terminal in responding to the stress of international competition but also act as a basis for decision-making with respect to continuing development in operational efficiency.

It should also be noted that several factors were not considered in this study due to the difficulty of obtaining data; these factors also have implications for the operational efficiency of ports and include factors such as labor, operational time, berth occupancy, and handling speeds of cranes. Terminal management, with regards to its terminal operations, should strive for complete and detailed data. It would be appropriate to consider some exogenous factors that may influence the container terminal's efficiency, such as hinterlands, GDP, type of ownership, and many others. Despite the above limitations, this study has revealed some interesting findings and contributed to the literature by revealing the efficiency of West African ports, as there has been limited study previously in the region. This being said, the derivation of the efficiency estimates for the West African ports evaluated in this study simply constitutes a beginning, rather than an end in itself. A challenge for academics and researchers is to attempt to involve the respective authorities in obtaining comprehensive and reliable data that will lead to deeper information on the industry. Further research should address these issues within the context of West African ports.

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References

1) United Nations Publications. In: Handbook of Statistics. 2018;p. 1–104.
2) Min H, Park BI. A hybrid Data Envelopment Analysis and simulation methodology for measuring capacity utilisation and throughput efficiency of container terminals. *International Journal of Logistics Systems and Management*. 2008;4(6):650–650. doi:10.1504/ijlsm.2008.019184.
3) Kutin N, Nguyen TT, Vallée T. Relative Efficiencies of ASEAN Container Ports based on Data Envelopment Analysis. *The Asian Journal of Shipping and Logistics*. 2017;33(2):67–77. doi:10.1016/j.ajsl.2017.06.004.
4) de Bruijn H. Performance measurement in the public sector: strategies to cope with the risks of performance measurement. *International Journal of Public Sector Management*. 2002;15(7):578–594. Available from: https://dx.doi.org/10.1108/09513550210448607. doi:10.1108/09513550210448607.
5) Notteboom T, Pallis A, Rodrigue J. Port economics, management and policy;vol. 624. New York. .
6) Tongzon JL, Ganesalingam S. An Evaluation of ASEAN Port Performance and Efficiency. *Asian Economic Journal*. 1994;8(3):317–330. doi:10.1111/j.1467-8381.1994.tb00020.x.
7) Steenken D, Voß S, Stahlbock R. Container terminal operation and operations research — a classification and literature review. *Container Terminals and Automated Transport Systems*;26:3–49. doi:10.1007/3-540-26686-0_1.
8) Hlali A. Efficiency Analysis with Different Models: The Case of Container Ports. *Journal of Marine Science: Research & Development*. 2018;08(02):8–8. doi:10.4172/2155-9910.1000250.
9) Kammoun R, Abdenadher C. The Technical Efficiency of Tunisian Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis Scores. *Journal of Marine Science: Research & Development*. 2018;08(06):8–8. doi:10.4172/2155-9910.1000261.
10) Mortimer D. Competing Methods for Efficiency Measurement A Systematic Review of Direct DEA vs SFA / DFA Comparisons. *Health economics*. 2002;27. Available from: http://chpe.buseco.monash.edu.au.

11) Cullinane K, Wang T. The efficiency analysis of container port production using DEA panel data approaches. *OR Spectrum*. 2010;32(3):717–738. doi:10.1007/s00291-010-0202-7.
12) Ds K, Dwarakish GIJH, Eng. Measuring port performance and productivity. *ISH Journal of Hydraulic Engineering*. 2018;26:1–7. Available from: https://doi.org/10.1080/09715010.2018.1473812.
13) Chang YTT. Environmental efficiency of ports: a Data Envelopment Analysis approach. *Maritime Policy & Management*. 2013;40(5):467–478. doi:10.1080/03088839.2013.797119.
14) Golany B, Storbeck JE. A Data Envelopment Analysis of the Operational Efficiency of Bank Branches. *Interfaces*. 1999;29(3):14–26. doi:10.1287/inte.29.3.14.
15) Valdmanis V. Sensitivity analysis for DEA models. *Journal of Public Economics*. 1992;48(2):185–205. doi:10.1016/0047-2727(92)90026-c.
16) Salinas-Jiménez J, Smith P. Data envelopment analysis applied to quality in primary health care. *Annals of Operations Research*. 1996;67(1):141–161. doi:10.1007/bf02187027.
17) Visbal-Cadavid D, Martínez-Gómez M, Guijarro F. Assessing the Efficiency of Public Universities through DEA. A Case Study. *Sustainability*. 2017;9(8):1416–1416. doi:10.3390/su9081416.
18) Cui Q, Yu LT. A Review of Data Envelopment Analysis in Airline Efficiency: State of the Art and Prospects. *Journal of Advanced Transportation*. 2021. Available from: https://doi.org/10.1155/2021/2931734.
19) Mescher M, Müller A. Data Envelopment Analysis. *Controlling*. 2002;14(4-5):299–300. doi:10.15358/0935-0381-2002-4-5-299.
20) Bassan S. Evaluating seaport operation and capacity analysis—preliminary methodology. *Maritime Policy & Management*. 2007;34(1):3–19. doi:10.1080/03088830601102725.
21) Tongzon J. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transportation Research Part A: Policy and Practice*. 2001;35(2):107–122. doi:10.1016/s0965-8564(99)00049-x.
22) Zaoudi A. Measurement and benchmark of economic performance in the Mediterranean port sector. *The 4th International Conference on Computers in Management and Business*. 2021;p. 13–19. Available from: https://doi.org/10.1145/3450588.3450592.
23) Manase M, Ngangaji F. An Assessment of Container Terminal Efficiency in East Africa Ports Using Data Envelopment Analysis (DEA)_ The Case of Dar Es Salaam & Mombasa Ports. *World Maritime University Malmö*. 2019.
24) Barros CP, Peypoch N, As AE. Evaluating the Location Efficiency of Arabian and African Seaports Using Data Envelopment Analysis (DEA). 2007;p. 1–19. Available from: https://pdfs.semanticscholar.org/0f35/f11fe446178e4ff7731bbdcdcb63a1cbf81f.pdf.
25) Dyck GKV. Assessment of Port Efficiency in West Africa Using Data Envelopment Analysis. *American Journal of Industrial and Business Management*. 2015;05(04):208–218. doi:10.4236/ajibm.2015.54023.
26) Herrera S, Pang G. Eficiency of Infrastructure: The Case of Container Ports. *Economia [Internet]*. 2008;9(1):165–194.
27) Liu BL, Liu WL, Cheng CP. The Efficiency of Container Terminals in Mainland China: An Application of DEA Approach. In: 2008 4th International Conference on Wireless Communications, Networking and Mobile Computing. IEEE. 2008;p. 1–10. doi:10.1109/wicom.2008.1479.
28) Chin ATH, Low JMW. Port performance in Asia: Does production efficiency imply environmental efficiency? *Transportation Research Part D: Transport and Environment*. 2010;15(8):483–488. doi:10.1016/j.trd.2010.06.003.
29) Maqbool MS, Anwar S, Tahir M. Technical Efficiency and its Determinants of Leather and Leather Products of Pakistan: A Data Envelopment Analysis Abstract. 2021;41:83–95.
30) Cullinane K, Song DW, Ji P, Wang TF. An Application of DEA Windows Analysis to Container Port Production Efficiency. *Review of Network Economics*. 2004;3(2):184–206. doi:10.2202/1446-9022.1050.
31) Wang TF, Cullinane K. The Efficiency of European Container Terminals and Implications for Supply Chain Management. *Maritime Economics & Logistics*. 2006;8(1):82–99. doi:10.1057/palgrave.mel.9100151.
32) Wanke PF, Barbastefano RG, Hijjar MF. Determinants of Efficiency at Major Brazilian Port Terminals. *Transport Reviews*. 2011;31(5):653–677. doi:10.1080/01441647.2010.547635.
33) Cheon S, Dowall DE, Song DW. Evaluating impacts of institutional reforms on port efficiency changes: Ownership, corporate structure, and total factor productivity changes of world container ports. *Transportation Research Part E: Logistics and Transportation Review*. 2010;46(4):546–561. doi:10.1016/j.tre.2009.04.001.
34) Notteboom T, Coeck C, Broeck JVD. Measuring and Explaining the Relative Efficiency of Container Terminals by Means of Bayesian Stochastic Frontier Models. *International journal of maritime economics*. 2000;2(2):83–106. doi:10.1057/ijme.2000.9.
35) Turner H, Windle R, Dresner M. North American containerport productivity: 1984–1997. *Transportation Research Part E: Logistics and Transportation Review*. 2004;40(4):339–356. doi:10.1016/j.tre.2003.06.001.
36) Wu G. The Impact of Inter-Company Network Technology on Correlations between Supply Chain Drivers and Performance Measures. The University of New South Wales Australi. 2009.