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Optimizing Cost Efficiency in Nigerian Port Operations: A Linear Programming Approach.

Pwara Kim E.[1*], Eru John U.[1], Ofurumazi Righteousness P.[1], Egelu Famous D.[1], Otakpor Ezinwa P.[1], Okonko Ifiokobong I.[2], Ottah Joshua K.[3]

Email: elkiakim@gmail.com, joneru2001@yahoo.co.uk, righteousness.ofurumazi@nmu.edu.ng, egeluf@gmail.com, otakporpeters@nmu.edu.ng, ifiokonko@gamil.com, ottahgot@gmail.com,

*Corresponding author. elkiakim@gmail.com

Affiliations: [1]Department of Transport and Nautical Science, Nigeria Maritime University, Delta State. [2]*Department of Maritime Management Technology, Federal University of Technology, Owerri, Nigeria.* [3]Department of Maritime Transport and Business Studies, Global Maritime Academy, Delta State

ABSTRACT

This study examined cost efficiency in port operations in Nigeria using linear programming as optimization tool. The objectives of the study were to develop a linear programming model that minimizes total port operational costs in Nigerian port operations and to determine the optimized model of cost of port operations in Nigeria. The study specifically considers operational variables such as Gang Time, Ship Turnaround Time, Warehouse Time, and Berth Occupancy. Secondary data were obtained from the Nigerian Ports Authority (NPA) annual port tariff. The result of the study indicates optimal operational cost of $26,471.11. This represents the least possible cost required to satisfy all the operational constraints. Of the seven parameters considered in the study which include Ship dues, Nigerian Ports Authority (NPA) towage dues, inner anchorage charges, berth rent, harbour dues, cargo dues), only three which include (Pilotage and towage, inner anchorage charges and cargo dues) contributed to the optimal solution, pilotage and towage = 8.00, inner anchorage = 3.389, and cargo dues = 5.25,the remaining Ship dues, Nigerian Ports Authority (NPA) towage dues, berth rent, and harbour dues were assigned zero values. This implies that not every operational activity has equal contribution to cost effectiveness. The model satisfied Ship dues at 288, Nigerian Ports Authority (NPA) towage dues at 244 and Pilotage and towage at 168, this indicate a precise allocation of resource to meet the minimum requirements. The study concluded that cost efficiency in Nigerian ports can be significantly improved when managers adopt resources optimization based allocation models. The study indicates that uniform deployment of all services may hamper cost optimization objectives; instead a strategic selection of activities is essential for optimizing port operational costs.

ARTICLE INFO

***Keywords:* Port Operations, Cost Efficiency, , Port Cost Optimization, Maritime Logistics**

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1. INTRODUCTION

Nigeria being the largest economy in Africa, depend on many sectors such as oil and gas, agriculture and now maritime. Interestingly, majority of Nigeria's international trade is seaborne, and port serve as one of the critical infrastructure for importing and exporting commodities. Seaports make the movement of commodities faster, commodities such as crude oil, natural gas, agricultural products, raw crudes and manufactured goods to foreign countries. Nigeria's major seaports such as Apapa, TinCan Island port, Onne, Delta and Port-Harcourt contributes immensely to trade and commerce, connecting Nigeria to global markets. The quality of infrastructures of the port and the logistics system is regarded as pivot industry that can lead to sufficient growth and development in emerging economy (Ndalu & Okene, 2024).

Buhari, Ndikom and Nwokedi (2017) examined the critical relevance of seaport and port operations to the economic development of the country, because it is the most single influential factor on maritime operations and logistics in terms of cost, productivity output, time, efficiency and effectiveness of operations, than other nodes and entities in the world supply chain network.

Beyond its mediating roles in seaborne trade, Onwuegbuchulam (2020) has observed that the seaport is also a strategic asset for national security and the economy, which had over the years grown in its importance to become a major component of the transport sector in general and the maritime subsector in particular. The maritime subsector encompasses a wide range of services and activities, which include the transportation of goods and passengers, commercial fishing, tourism, cruise shipping, and naval and maritime security.

African maritime trade significantly increased by 5.6% in 2021, resulting in a cumulative volume of 1.3 billion metric tons (UNCTAD, 2022). Despite the generally underdeveloped state of Africa's maritime transport industry, most imports and exports in the region, over 90%, are conducted through seaborne trade via coastal ports (African Union, 2019). A substantial share of global trade passes through West African ports, inclusive of Nigerian seaports. It generates significant economic value for these regions. Every port in these locations aims to become more efficient in attracting more vessels and improving revenue. Due to their large populations and rapid GDP growth, investors consider this region Africa's central marketplace (Gamassa and Chen, 2017). The idea of port operations being provided at a cost and profit suggests the enthronement and/or ushering in of a competitive era, where price, quality and value of port service rendered becomes major variables that motivate shippers, ship owners and other categories of port user's choice of port and/or terminal of call (Jenkins 2018 and UNCTAD 2020).

In the midst of these benefits and contribution of the seaports, high charges like increase in the cost of port usage has led to less demand for port services. Also, optimal charges can minimize the cost of port consumption, thereby increasing demand for port services. Such optimization has the potential to positively influence the productivity, efficiency and the overall maritime sector development in Nigeria (Melnyk,Shcherbina, Mykhailova, Obnyavko, and Korobko 2023).

Thus port authorities are known to charge various categories of rates as prices for consumption of varied port service types. For example, a report by the Nigeria Ports Authority (NPA, 2026) listed the following rates and tariffs as prices charges by the NPA for various service types:

(i) Throughput Fee: The throughput fee is a fee charged by the Port Authority for the volume of cargo inward and outward cargo traffic transiting through the concession terminal. The basis of measurement is in TEUS and Tons. It is chargeable to and paid payable by the Terminal Operators (NPA, 2019).

(ii) Lease Fee: This a fixed annual payment of a sum specified in the Agreement to be paid in twelve (12) equal installments or on annual basis in each operating year paid by the terminal operators.

(iii) Wharfage: It is a charged assessed against goods of all description passing through wharf, whether they are general cargo, bagged cargo, liquid in bulk or in containers, dry cargo, unitized, ship's stores and bunker, animals and persons unless specifically exempted and shall be in addition to other charges. This is charged to and payable by the shippers. The basis of measurement of wharfage is in Tons.

(iv) Cargo Dues: According to Nigeria Ports Authority (NPA, 2026), cargo dues includes the following but not limited to them; Stevedoring: Including Overtime, Extra Services (Labour a, Security and Tally Clerk), Delays weekend Charge, b Optional Services and Facility Charge c (for Containers), Harbour Dues, Environmental Protection Levy, Labour – Services provided and not related to tonnage shall be charged accordingly, Delays – Operational delays due to ship arrangement, including non-provision of trucks shall be charged accordingly and facility Charge – A facility charge of ₦7.50 per ton at appropriated area shall be charged.

(v) Berthing/Mooring Dues: According to NPA (2026) it is a levy charged on vessel that make fast alongside or casts off from a Wharf in a Port or Harbour where boats or boat crew are provided by the Authority to run and secure lines, or for every vessel making fast to a mooring. The levy is also charged when vessel is made fast to already fastened vessel.

(vi) Ship Dues: According to NPA (2026), ship dues cover all services normally required by a vessel for her movement in to and out of the Port, including the use of Tug Boats.

(vii) Harbour Dues: This charge is applicable to all goods discharged or loaded and to all passengers embarked or disembarked within the harbour. It is also a charge for the facilities put in place to create a secured harbour for the berthing of a vessel to enable safe discharge/loading of cargo (NPA, 2026).

(viii) Conservancy: It is a charge that applies for the act of regulating and sustaining required standard of safety for ship in the waterways, through activities of Dredging, Sweeping, Lighting, Wreck removal, Provision of aids to navigation and other activities necessary for safe movement of ships in and out of the ports. (NPA, 2026).

(ix) Pilotage Dues: Pilotage is the charge, calculated in accordance with Pilotage rates and assessed against ship for the services rendered or proffered in piloting the ship on entering, leaving or shifting in a port. The safe navigation of ship, including piloting in a Compulsory Pilotage District is at all times the paramount duty of a ship's master and the presence of an Authority's Pilot on the bridge shall in no way relieve the master of his duties and responsibilities (NPA, 2026)

(x) Anchorage Dues

Anchorage is created within pilotage districts for the purpose of providing shelter for vessels calling at or departing from ports. The anchorage affords vessels and ports the opportunity to plan for the arrival/berthing of vessels as well as provide waiting places for them prior to outward movement (NPA, 2026). Some of the charges and dues listed above formed the variables that was minimized for the ports to function at its optimal capacities.

Ports play a central role in national and regional economic development by facilitating bilateral and multilateral trades, making the all-round movement of raw materials and finished products seamless around the globe. It is one of the ways goods are moved within West and Central Africa. West African ports are becoming very important in the Global trade and it is expanding in capacity to handle containers. The challenges encountered by some of these container ports in Africa are still persistent. Despites the general relevance, Nigerian ports continue to face major challenges related to operational cost, issues related to inefficiency, irregular allocation of port resources, administrative bottlenecks, poor regulation and suboptimal service delivery (Olapoju 2023; Nze & Onyemechi, 2018; Fraser & Notteboom, 2016; Tongzon, 2009; Ndikom, 2013).

There is a seeming lack of quantitative optimization models like Linear Programming (LP) to Nigerian port cost structures, which is a major evidence gap. Without a strong quantitative framework to guide resource allocation to minimize cost, port operators may rely on improvised or exploratory decision making, thereby limiting both operational performance and futuristic planning. Therefore, there is need to apply linear programming models to port operations in Nigeria to derive empirically grounded optimization strategies that can reduce operational costs while improving throughput and service quality. Thus, the study was carried out to close this gap which will contribute immensely in decision in the port business and have a comparative advantage over their competitor.

1.1 Aim and Objectives of the Study

The aim of this study is to investigate cost efficiency in Nigerian port operations by applying Linear Programming models to optimize the allocation and utilization of port services and NPA tariff-based charges for conventional vessel import and export operations, the specific objectives of the study includes;

1. To develop a Linear Programming model that minimizes total port operational costs in Nigerian port operations.
2. To determine the optimal cost of port operations in Nigeria.

2. LITERATURE REVIEW

Omoju, Emenike, and Kalu (2021) the study evaluated optimization as a quantitative approach to minimizing the costs of terminal operations in comparison with the routine (trial and error) approach found to be employed by terminal operators in Nigerian ports. In carrying out the experimental survey, the researcher used a five-year throughput data of dry and liquid bulk cargoes from a bulk terminal operator at Port Harcourt NPA Port were collected from 2015 to 2019 to serve the routine approach purpose. In parallel an objective function was modelled to minimize the costs of cargo handling subject to identified constraints that produced the optimal solutions for the optimized data. A test of hypothesis was conducted to determine if the means (μ) of the two sets of data (optimization and routine) were significantly different from each other using the student t-test statistic. At 95% level of significance, degree of freedom (df) 4, the results revealed that there was no significant difference between the two data sets. The study concluded with the implications for the study and the need to train both the terminal operators and the ports authority in the use of the optimization techniques for an integrated to tackling port operational challenges.

Ifeanyi, Salam, and Iruoghene (2024) conducted a study that is driven by the objective to assess the impact of the seaport efficiency on Nigeria's economic growth. The western ports of Lagos were selected as the Decision-Making Units (DMU) for the study covering the period of 2000 to 2020. Two stage estimation process was employed. Data Envelopment Analysis (DEA) was deployed to generate the efficiency index required to test the relationships. In the second stage, the efficiency index so generated was introduced as one of the independent variables in a multiple regression model, using Autoregressive Distributed Lag Model (ARDL). The finding shows that seaport efficiency has a negative but significant relationship with economic growth in both the long run and short run. The study concludes that seaport efficiency has an inverse relationship with Nigeria's economic growth. The result of this study suggests that reforms may not have deepened the level of efficiency in the Nigerian seaport to drive positive economic growth, hence the recommendation for further investment in the terminal operational equipment and technological infrastructure to drive further efficiency in the sector.

According to the work of Felix (2025) maritime transport is crucial for global trade and economic development: port efficiency and productivity boost trade competitiveness and growth. Improving port efficiency speeds the transportation of goods and reduces logistics costs and delays. West African ports have recently handled more containers, indicating their growing significance in global trade. Despite this expansion, West African ports need to enhance their performance. The stud applied the DEA-SBM model and Malmquist Productivity Index (MPI) to six West African (Benin Republic, Côte d'Ivoire, Ghana, Nigeria, Togo, and Senegal) ports from 2010 to 2022 to evaluate operational efficiency and productivity. The DEA-SBM model reveals that Tema (Ghana), Lome (Togo), and Abidjan (Côte d'Ivoire) ports have optimal efficiency at different periods, unlike Apapa (Nigeria), Cotonou (Benin Republic), and Dakar (Senegal). On average, operational efficiency scores range from 0.6 to 0.8, indicating resource overuse and inconsistency. The DEA-MPI shows that most ports have experienced improvements in total factor productivity (TFP), mainly due to technological and efficiency advancements. While some ports have grown slowly, overall development is crucial. This study recommends strategic planning and collaboration between port management bodies and governments to preserve efficiency and productivity, including setting practical requirements.

Caleb, Sarah, Panagiotis, Lijun and Chukwuneke (2024) suggested in their study that container ports play a pivotal role in international trade, facilitating the movement of goods and fostering economic development. While much attention has been given to the efficiency of ports in high-income countries, container ports in lower middle-income (LMI) countries have received less attention. A cross-sectional data for the year 2012 was collected for 53 container ports in LMI countries. The study utilizes data envelopment analysis, which offers the advantage of considering multiple inputs and outputs. The results show that the overall technical inefficiencies of LMI countries' container ports are mainly due to pure technical inefficiency rather than scale inefficiencies, and the most efficient ports have a combination of large and hub ports. They also reveal that larger ports (as measured by throughput) are not necessarily more efficient than ports with a small production scale. The results of this research can provide government authorities, port authorities, terminal operators, and investors with valuable insights into resource allocation, competitive advantage, and optimization of operating performance.

According to Gloria, Yu and Esther, (2021) opined that ports are one of the assets of every country and one way to achieve efficiency is by maximizing productivity amid limited resources. The study evaluated the technical efficiency of the 5 major container terminals in the West African region. The Data Envelopment Analysis (DEA) approach was 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. 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.

Another work by Ibeawuchi, Innocent, Nnadi, Callistus (2016) on modelling the relationship between demand for River port services and vessel supply costs. The quantitative estimates from this study are concerned with the activities associated with the operations of Nigerian river ports as well as the costs and the benefits derived to users of these ports. A structural equation model (SEM) of the river port operations was derived and estimated by the application of LISREL software to generate reduced form of equations and parameter estimate. The results of the SEM technique shows that the demand for port services is significantly related to vessel supplies cost. The study concludes that Inland waterways transportation has a significant contribution to economic development of Nigeria, if the potentials are fully harnessed. Therefore, it is recommended that government should enforce sustainable legislation to make IWT operations attractive to private organizations for optimal benefits.

The work of Asiegbu, and Nze (2013), with the title "optimization of costs of port operations in Nigeria: a scenario for emerging river ports". The study attempts to optimize the cost of port operations in Nigeria. The quantitative estimates are concerned with the activities associated with the operations of Nigerian ports, the costs and the benefits derived by users of these ports. A Linear Programming Model was formulated from the cost components associated with the vessel-port relationships. With the aid of QM for Windows Software, an optimal solution was derived. The result shows the minimum cost of port operations as well as determining the optimal time frames for the decision variables of port operations. This provides a basis for future projection to determine the range of values of the constraints and decision variables for which the solutions will continue to be optimal.

Maria, Nuno, Francisco, Miguel and Marisa (2025) suggested that ports are essential nodes in global trade linking maritime and land transport. As maritime logistics increasingly drive global supply chains, optimizing port operations has become vital for enhancing economic efficiency and environmental sustainability. The study presents a Mixed Integer Linear Programming (MILP) model to address inefficiencies in berth allocation and stevedoring processes at the Port of Leix.es, Portugal. By integrating real operational data, the model reduces vessel waiting times by 47.56% (from 8.1 to 4.2 h) and operational delays by 37.39% (from 11.5 to 7.2 h). The model's innovations include real-time data integration and a holistic resource allocation approach to mitigate congestion and inefficiencies. Key findings from the study demonstrate the model's potential to streamline operations.

According to the work of Manuel, Juan, Ignacio and María (2025) the study presents a methodology for determining port economic hinterlands through comprehensive logistics optimization. The research advances traditional geographical approaches by developing an integrated cost model that considers maritime transport, inland transportation, warehousing expenses, and time-dependent factors. Testing this methodology on the Spanish port system (with three main ports: Valencia, Algeciras, and Barcelona). The approach contributes to port competition theory by establishing a quantitative framework for dynamic hinterland delineation based on actual logistics costs and operational factors.

According to the work of Souhir (2014) the measurement and evaluation of seaport competitiveness is of important academic interest, as it is reflected in the increasing amount of international literature in this field. However, in the light of very limited empirical studies about port economics for Africa, this paper aims at identifying the major determinants of competitiveness of the African seaport systems. This was accomplished using Principle Component Analysis. Based on 7-year longitudinal data for 14 countries in North and West Africa, this study shows that handling costs, connectivity, capacity and the quality of port infrastructure are important in explaining port competitiveness. As expected, North African seaports were found to be more competitive than those in the West. This article provides an important literature review on port competitiveness. The empirical study can also contribute substantially to the knowledge of the African seaport systems and be useful for African port policy development and management.

Table 1: Ease of Doing Business Comparison

Country/Economy	Ease of Doing Business Rank	Doing Business score 2019	Doing Business score 2018	Trading across borders rank	Trading across borders 2019	Trading across borders 2018
Global Best Practice Countries assessed						
Morocco	60	71.02	68.56	62	83.58	81.12
Singapore	2	85.24	84.97	45	89.57	89.57
South Africa	82	66.03	64.66	143	59.64	59.73
Spain	30	77.68	77.61	1	100	100
West Africa Countries assessed						
Benin	153	51.42	51.29	107	68.94	68.94
Cote D' Ivoire	122	58.00	53.06	162	52.44	52.44
Ghana	114	59.22	57.16	156	54.84	52.32
Nigeria	146	52.89	51.52	182	23.08	19.93
Senegal	141	54.15	53.78	139	60.85	60.85
Togo	137	55.20	48.88	129	63.66	63.66

Source: Jon, Christopher, Mike and Moses (2019), Comparative Assessment of Tariffs/ Costs at ports along the West Africa Coast

The World Bank conducts the 'Ease of Doing Business' assessment annually, generating the ease of doing business scores of absolute levels of regulatory performance over time. This captures the gap of each economy from the best regulatory performance observed on set of indicators, across all economies for *Doing Business* (World Bank, 2019).

According to Jon, Christopher, Mike and Moses, overall, Nigeria ranks among the lowest on the Ease of Doing Business at 146 and 182 for the Trading Across Borders ranking out of 190 countries assessed, and this attributable to exorbitant cost of port operations which has discouraged major investors into the Nigerian port domain, although better than Republic of Benin, 153 in the region for ease of doing business.

Singapore can be considered one of the best countries for ease of doing business, but Spain is top on the Trading across Borders ranking. This implies there are other contributory factors aside from trade facilitation that may also influence ease of doing business in a country. Owing to the relatively good

performance of Spain and Singapore in trade facilitation and doing business, this study further examines key competitiveness factors of their ports amongst other

Table 2: Trading Across Border Analysis: Time and Costs for Imports and Exports

Country/ Economy	Trading across boarder (score)	Trading across boarder (rank)	Time to export: Border compliance (hours)	Cost to export: Border compliance (USD)	Time to export: Documentary compliance (hours)	Cost to export: Documentary compliance (USD)	Time to import: Border compliance (hours)	Cost to import: Border compliance (USD)	Time to import: Documentary compliance (hours)	Cost to import: Documentary compliance (USD)
Spain	100	1	0	0	1	0	0	0	1	0
Singapore	89.57	45	10	335	2	37	33	220	3	40
Morocco	83.58	62	11	156	26	107	65	228	26	116
Benin (WA)1	68.94	107	78	354	48	80	82	599	59	110
Togo (WA)	63.66	129	67	163	11	25	168	612	180	252
Senegal (WA)	60.85	139	61	547	26	96	53	702	72	545
South Africa	59.64	143	92	1257	68	55	87	676	36	73
Ghana (WA)	54.84	156	108	490	89	155	80	553	36	474
Cote d' Ivoire (WA)	52.44	162	239	423	84	136	125	456	89	267
Nigeria (WA)	23.08	182	135.4	785.7	119	250	263.7	1076.8	144	564.3

Source: Jon, Christopher, Mike and Moses (2019), Comparative assessment of tariffs/ Costs at ports along the West Africa Coast

The ranking is based on 8 indicators for time and costs on imports and exports as seen in table 2.

TAB scores and rankings can be attributed to ports efficiency, which is an important determinant of shipping costs. Inefficient ports also evidence higher handling costs which are one of the components of shipping costs. Variations in port efficiency have been noted to be linked to excessive regulation, the prevalence of organized crime and the general condition of the country's infrastructure (Jon et al., 2019).

Table2 also shows country's performance in relation to the World Bank TAB indicators, for comparator countries selected for this study. It is interesting to note that South Africa does not score too high for TAB, in spite of Durban Port being considered effective and competitive, particularly in relation to principal activities of automotive related imports and fruit/produce exports. This indicates that the relatively high costs of using South Africa's ports are outweighed by the efficiencies provided to port customers and the predictability delivered. Whilst relatively high port related costs may be an inhibitor for certain types of trades and cargoes, there is a strong assertion that predictability and

reliability have become increasingly important parameters affecting choice of routings within supply chains (Jon et al., 2019).

3. DATA AND METHODS

In order to satisfy the objective of the study a linear programming technique is applied. Linear programming is a mathematical technique concerned with the allocation of scarce resources. It is a procedure adopted to optimize the value of some objectives functions subject and some constraints. The technique involves formulating a given problem as a linear programming model with the variables clearly identified and using standard techniques to solve the problem.

As is often formulated, linear programming seeks to find non – negative values of the variables X_1, X_2, X_3, X_4 X_5, X_6, X_7, ……., X_n that satisfy the constraints: $a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \ldots\ldots\ldots a_{i1n}xn = b$,where I = 1,2,3…..m, that maximizes or minimizes the linear form $C_1X_1 + C_2X_2 +$ …….CnXn. The essence is to reconcile the seeming apathy towards linear programming techniques with the benefits derived therein. These variables are manipulated to produce solution which is improved upon until the optimum solution is reached. To capture all the issues involved, our discussion will focus on the following key areas.

Optimize (Min.) $Z = c_1x_1 + c_2x_2 + \ldots + c_n x_n$
Subject to the linear constraints,
$a_{11}x_1 + a_{12} x_2 + \ldots + a_{1n} x_n (\leq, =, \geq) b_1$
$a_{21}x_1 + a_{22} x_2 + \ldots + a_{2n} x_n (\leq, =, \geq) b_2$

$a_{m1}x_1 + a_{m2} x_2 + \ldots + a_{mn} x_n (\leq, =, \geq) b_m$
and
$x_1, x_2, \ldots. X_n \geq 0$
The above formulation can also be expressed in a compact form as follows:

Optimize (Min.) $Z = \sum_{j=1}^{n} Cj\ Xj$ Objective function (1)

Subject to the linear constrain\
$\sum_{j=1}^{n} aij\ Xj (\leq, =, \geq)$ bi, i = 1,2 ,…..m (Constraints) (2)
and
$Xj > 0$; j = 1,2,….n (Non-negativity conditions) (3)

Where decision variables are:
X_1 = Ship Dues
X_2 = NPA Towage Service
X_3 = Pilotage and Towage
X_4 = Inner Anchorage Charges
X_5 = Berth Rent
X_6 = Harbour Dues
X_7 = Cargo Dues

4. RESULTS AND DISCUSSION

The Linear Programming Model is obtained as follows (Objectives Function)

Minimize Z = $9,897.17X_1 + 14,950X_2 + 2,662.5X_3 + 1,421.95X_4 + 3677.28X_5 + 86.34X_6 + 67.10X_7$

Constraints Subject to:

$48X_1 + 24X_2 + 36X_3 \geq 288$

$72X_4 + 60X_5 \geq 244$

$40X_6 + 32X_7 \geq 168$

$24X_2 + 18X_5 + 36X_7 \geq 144$

Non-Negative Condition

$X_1, X_2, X_3, X_4, X_5, X_6, X_7 \geq 0$

The optimum solution using excel for windows software is

Z = Minimum cost of port operations = $26471.11

$X_1 = 0$

$X_2 = 0$

$X_3 = 8$

$X_4 = 3.388889$

$X_5 = 0$

$X_6 = 0$

$X_7 = 5.25$

Table3: Linear Programming Model

Port Activities	Gang Time	Ship Turnaround Time	Warehouse Time	Berth Occupancy	Unit Cost
	288	244	168	-	
Ship Dues (X_1)	48	-	-	-	9,897.17
NPA Towage Service (X_2)	24	-	-	24	14,950.00
Pilotage and Towage (X_3)	36	-	-	-	2,662.50
Inner Anchorage Charges (X_4)	-	72	-	-	1,421.95
Berth Rent (X_5)	-	60		18	3,677.28
Habour Dues (X_6)	-	-	40	-	86.34
Cargo Dues (X_7)	-	-	32	36	67.10

Source: Authors Computation based on NPA Tariff Schedule, 2026

The Table3 above shows the relationship between different port operational activities, the contribution of these activities and the cost associated with them. This is the focal point of the optimization analysis, it identifies how each activity support the requirements for port operation, such as Gang Time, Ship Turnaround Time, Warehouse Time and Berth Occupancy.

Each decision variable contributes differently across the operational constraints. For instance, ship dues (X_1) contributes 48units to Gang Time at a relatively high unit cost of 9,897.17, while pilotage and towage (X_3) contributes 36 units to the same constraint at a much lower cost of 2,662.50. This simply means that X_3 offers a more cost effective option for meeting gang time requirements. Also, cargo dues (X_7) stands out as the most economical variable, with the unit cost of 67.10 while still contributing 32 units to Warehouse time and 36 units to berth occupancy. Its dual contribution across constraints makes it highly valuable in the optimization process. On the contrary, NPA towage service (X_2) has the highest unit cost of 14,950.00 despite contributing only 24 units to gang time and 24 units to Berth Occupancy, indicating lower cost efficiency. It is clear that operational demands are distributed, 288 units for gang time, 244 units for ship turnaround time, and 168 units for warehouse time. This forms the basic requirements to satisfy the optimization model. In conclusion, the table above demonstrates that port activities vary significantly in both cost and operational contribution.

Table4: Ranging Table

Variable	Original Value	Calculated Value
X_1	9,897.17	**0**
X_2	14,950.00	**0**
X_3	2,662.50	8.000
X_4	1,421.95	3.389
X_5	3,677.28	**0**
X_6	86.34	**0**
X_7	67.10	5.250

Source. Model from Excel Solver.

This table presents a comparison between the original unit cost values of each decision variable and their calculated optimal vales obtained from the linear programming solution. The results show that X_3, X_4 and X_7 have positive calculated values; this means they were included in the optimal solution. Specifically, X_3 = 8.000, X_4 = 3,389, and X_7 = 5.250, these variables therefore formed the most cost efficient combination for satisfying the operational constraints. On the contrary, X_1, X_2, X_5 and X_6 all have calculated values of 0, indicating that they were not selected in the optimal allocation; this suggests that, despite their operational relevance, they are less efficient under the cost minimization scope when compared with the chosen variables. A closer look at the original values explains this pattern. X_2 has the highest unit cost at 14,950.00, making it the least attractive option in the optimization model. In contrast, X_7 with the lowest unit cost of 67.10, remains active in the solution, confirming its strong cost effectiveness. Interestingly, X_6 also has a low unit cost of 86.34, yet it was not selected, showing that inclusion depends not only on cost but also on the variable's contribution to meeting constraints.

Table5: Variable definition table – Table Solution List

Variable	Status	Value
X_1	Non basic	0
X_2	Non basic	0
X_3	Basic	8
X_4	Basic	3.388889
X_5	Non basic	0
X_6	Non basic	0
X_7	Basic	5.25
Optimal value(Z)		**26471.11**

Source: Model Run from Software

The Variable Definition Table5 summarizes the final solution structure of the linear programming model by classifying each decision variable as either basic or non-basic, alongside its corresponding value in the optimal solution. This table shows that some variables basic while others are non-basic, variables such X_3, X_4 and X_7 with corresponding values of 8.00, 3.389 and 5.250 are variables that directly contribute to satisfying the operational constraints and form the core of the least cost allocation strategy. The other non-basic are X_1, X_2, X_5 and X_6 with zero values. These non-basic variables are not included in the optimal solution because they do not improve the objective functions under those given constraints. There will an increment if resources are allocated without offering additional optimization benefits.

The optimal value of Z = 26,471.11represents the minimum total operational cost achievable while meeting all models requirements. This value confirms the success of the optimization process in identifying the most economical allocation pattern. The table above demonstrates that only a few strategically chosen variables are necessary to achieve efficiency at the lowest possible cost.

4.1 Discussion of Findings and Policy Implications

The findings of this study suggest that linear programming model is a effective tool that provide an accurate pattern that is used to achieve cost efficiency in Nigerian port operations. After minimizing the objective function, an optimal operational cost of 26,471.11 was obtained, this value represents the least possible cost or expenditure required to satisfy all the operational constraints. With the consistent rise in cost affecting the conventional business in port environment, through the finding, it is clear that quantitative optimization can assist in making decisions for managers especially with the limited resources.

One major finding from the study is that out of the seven variables in study only three contributed to the optimal solution, X_3 =8.00, X_4 = 3.389, and X_7 = 5.25,the remaining X_1, X_2, X_5, and X_6 were assigned zero values. This simply means that not every operational activity has equal contribution to cost effectiveness, hence instead of spreading resources across all service category, the model selected activities that required outputs at minimum cost. This finding is actually related to the principle of resource prioritization, where management focuses on investing on the most economically viable services.

The result also reveals the relevance of balancing cost coefficients with constraints contributions. For instance, variable X_2 having the highest initial unit cost of 14,950 was not part of the solution, this is because cost efficiency does not depend only on the absolute price of a variable but how effectively it satisfies operational requirements, like the case of X_7 with the smallest unit cost of 67.10 with 5.25 units, this indicates that variables that offer greater contribution at lower relative cost become more valuable in an optimized system.

Also, there is an operational feasibility insight via the constraint analysis. The model satisfied constraint 1 at 288, constraint 2 at 244 and constraint 3 at 168, this indicate a precise allocation of resource to meet the minimum requirement, but constraint 4 recorded 189 against the required 144, creating a surplus of 45units, as a result of this surplus a margin of service capacity is introduced, indicating that the optimized solution does not meet operational demand, this kind of flexibility can be helpful in port operations, because an unexpected fluctuations in cargo demand or service needs may arise.

Previous research, like the work of Asiegbu and Nze (2013) and Omoju et al. (2012) established that linear programming can minimize operational cost in Nigerian ports. With Excel Solver approach, the present study extends by displaying the exact allocation that is required for cost efficiency. This indicates that the model provides evidence based guidance that can be easily implemented by port managers.

Other researchers that used the DEA approach succeeded in identifying if a port is efficient compared to others, but it was unable to prescribe the optimal combination of activities to achieve minimization, hence we can conclude that DEA based studies satisfy efficiency scores, while this study contributes an operational decision making dimension. Hence, this study fills the gap created by DEA based studies by translating efficiency theory into actionable allocation strategies.

5. CONCLUSION

In conclusion, the findings indicate that cost efficiency in Nigerian ports can be significantly improved when managers adopt optimization based allocation models. This study suggests that uniform deployment of all services may hamper minimization instead a strategic selection of activity is essential for minimizing costs. This is typical provision of both practical and theoretical implications for port administrators, policymakers, and logistics planners seeking sustainable improvements in port performance.

6. RECOMMENDATIONS

In light of the empirical findings, the following recommendations are proposed:

(i) Implement Strategic Activity Selection Over Uniform Service Deployment: Port authorities should transition away from deploying all port services uniformly. Resource allocation must be restricted strictly to high-efficiency, cost-minimizing operational variables, specifically

Pilotage/Towage (X_3), Inner Anchorage Charges (X_4), and Cargo Dues (X_7) while minimizing or eliminating reliance on high-cost, low-yield inputs such as standard NPA Towage (X_2).

(ii) Institutionalize Quantitative Optimization to Maintain Least-Cost Port Operations: The Nigerian ports and terminal operators should adopt linear programming models as standard decision-making tools. Utilizing optimization algorithms ensures that port charges and resources schedules are continuously configured to keep total operational expenditure at the optimal baseline of $26,471.11 per vessel call while meeting all physical operational constraints

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APPENDIXES

Data Set obtained from NPA Annual Tariff

Table 6: Ship Dues

Type of Vessel	Service	Rate and Unit of Measurement	Berthing/ Mooring (USD)	Constant
Foreign	Without NPA 3rdParty Towage	USD 1.47GRT	-	1352
Foreign	With NPA 3rd Party Towage	USD 1.47GRT	287.5	-
Tropical WestAfrica	Without NPA 3rdParty Towage	USD 0.71GRT		1352
Tropical West Africa	With NPA 3rd Party Towage	USD 0.71GRT	287.5	-
Coastal	Without NPA 3rdParty Towage	USD 0.51GRT	-	1352
Coastal	With NPA 3rd Party Towage	USD 0.51	287.5	-
NLNG		1.47 GRT		1352
Shifitng (within Port or Pilotage District)		USD0.08 GRT		1352
Second Port of Call Same Voyage and call to repair yard		USD 1.08GRT		1352
Average	**SHIP DUES = $9,897.17 = ₦13,379,793.31**			

Source: NPA Simplified Annual Tariff

Table 7: NPA Towage Services (USD)

LOA OF VESSEL	RATE (USD)	UNIT OF MEASUREMENT
1 – 200 LOA	USD 2300	Per Tug/Movement
201 – 250 LOA	USD 2875	Per Tug/Movement
251 – 300 LOA	USD 4025	Per Tug/Movement
Above 300 LOA	USD 5750	Per Tug/Movement
Towage Service at Dangote SBM	USD 600	Per Tug/Hour
Average	**TOWAGE COST = $14,950 = ₦20,209,410**	

Source: NPA Simplified Annual Tariff

The Rates listed above shall apply to all pilotage districts deploying third party towage service. Minimum of two tugs shall be required for each movement of inward and outward. Uncharted channels within Pilotage Districts shall be GRT of the vessel multiplied by rate as in Schedule 1 (Part i) + 1352. Pilotage districts operating without Third Party shall charge the rate as in schedule 1 (Part i). Moves within ports in the same pilotage district shall attract a flat rate of $600 per Tug per Movement Using Tugs to assist a ship to swing/turn shall attract a flat rate of $600 per Tug per Assistance. The Delay of Tug Boat shall attract a fine of $400 per hour or part thereof, in addition to the fine for Delay of Pilot (detention) at the same rate.

Table 8: Pilotage and Footage Dues for Conventional Vessels

Pilotage District	Pilotage Due	Footage Due	Pilotage service
	USD	USD	USD
LAGOS PILOTAGE	0.08	0.05	0.13
WARRI PILOTAGE	0.17	0.10	0.28
BONNY PORTHARCOURTPILOTAGE	0.16	0.09	0.25
CALABAR PILOTAGE	0.16	0.09	0.25
Average	**$2,662.5 = ₦3,599,793.75 per vessel call**		

Source: NPA Simplified Annual Tariff

According to NPA annual tariff (2026) Administrative Fee shall be charged as follows:
Conventional Vessel: 50% of Footage Dues
Service Boat: 20% of Footage Dues. For service boats not boarded, the authority shall retain 60% of the pilotage and towage due computed for the concerned pilot, while the Pilot will be entitled to 40% only, for endorsing relevant documents and taking responsibility for safe passage.

Table 9: Charges for Inner Anchorage

Type Of Vessel	Rate	Unit of Measurement
FOREIGN FLAG VESSEL: 1 TO 30 LOA	0.17	Per GRT/Number of Days
FOREIGN FLAG: ABOVE 30 LOA	0.22	Per GRT/Number of Days
TWA: 1 TO 30 LOA	138.00	Per Number of Days
TWA: ABOVE 30 LOA	172.50	Per Number of Days
NIGERIAN FLAG VESSEL: 1 TO 30 LOA	NGN28750	Per Number of Days
NIGERIAN FLAG VESSEL: ABOVE 30 LOA	NGN40250	Per Number of Days
Average	**$1,421.95 = ₦1,920,051.33**	

Source: NPA Simplified Annual Tariff

Maximum of 72 hours is given as free period for any vessel using the Inner Anchorage before charges commence. Home Port Vessels (Pilot Boats, dredger, Utility Boats working within the port shall not pay Inner Anchorage Dues, provided they are paying Annual Dues, (Conservancy, Pilotage Exemption Certificate, etc) (NPA, 2026).

Table 10: Berth Rent (USD)

Type Of Vessel	Rate USD	Unit Of Measurement	Number of days
Container and RORO Vessels	2.3	LOA	2
Combo Vessels	2.3	LOA	3
Liquid Bulk Cargo Vessels	2.3	LOA	4
Dry Bulk Cargo Vessels	2.3	LOA	8
General Cargo Vessels	2.3	LOA	10
Averaage	Berth Rent Representative Cost =$3677.28= ₦4,968,000		

Source: NPA Simplified Annual Tariff

Table 11: Harbour Dues (USD)

Area	Cargo Type	Unit/Tonnage	Foreign		TWA/Coastal	
			Import(USD)	Export (USD	Import(USD)	Export (USD
Concession Area	General Cargo	Per Ton	2.88	1.96	2.30	1.38
	Liquid Bulk	Per Ton	2.17	1.91	1.68	1.68
	Dry Bulk	Per Ton	2.17	1.91	1.68	1.68
	Container 20 FT Empty	Per Unit	-	-	-	-
	Container 20 FT Laden	Per Unit	92.00	54.05	54.05	54.05
	Container 40 FT Empty	Per Unit	-	-	-	-
	Container 40 FT Laden	Per Unit	184.00	106.95	106.95	106.95
	Vehicle Up to 15 CBM	Per Unit	31.63	31.63	31.63	31.63
	Vehicle 16 to 25 CBM	Per Unit	51.75	51.75	51.75	51.75
	Vehicle above 25 CBM	Per Unit	215.05	215.05	215.05	215.05
	Vehicles up to 40 CBM	Per Unit	345.00	345.00	345.00	345.00
Vehicles above 120 CBM to be treated as General Cargo using tonnage or CBM , whichever one is higher						
	General Cargo	Per Ton	2.88	1.96	1.15	1.15
	Liquid Bulk	Per Ton	4.23	2.88	2.88	2.88
	Dry Bulk	Per Ton	2.88	1.96	1.15	1.15
	Container 20 FT Empty	Per Unit	-	-	-	-
	Container 20 FT Laden	Per Unit	90.13	90.13	90.13	90.13
	Container 40 FT Empty	Per Unit	-	-	-	-
Private Jetty(Harbour Dues)	Container 40 FT Laden	Per Unit	177.47	177.47	177.47	177.47
	Vehicle Up to 15 CBM	Per Unit	31.91	31.91	31.91	31.91
	Vehicle 16 to 25 CBM	Per Unit	52.61	52.61	52.61	52.61
	Vehicle above 25 CBM	Per Unit	215.91	215.91	215.91	215.91
	Vehicles up to 40 CBM	Per Unit	345.86	345.86	345.86	345.86
Vehicles above 120 CBM to be treated as General Cargo using tonnage or CBM , whichever one is higher						
	General Cargo	Per Ton	1.59	1.38	1.71	1.17
	Liquid Bulk	Per Ton	2.17	2.15	1.67	1.67
	Dry Bulk	Per Ton	1.62	1.46	1.37	1.21
	Container 20 FT Empty	Per Unit	0.00	0.00	0.00	#REF!
	Container 20 FT Laden	Per Unit	52.65	36.94	48.20	28.37
	Container 40 FT Empty	Per Unit	0.00	0.00	0.00	0.00

Appropriated Area(Harbour Dues)	Container 40 FT Laden	Per Unit	125.57	81.28	108.02	31.49
	Vehicle Up to 15 CBM	Per Unit	31.68	25.74	31.63	25.74
	Vehicle 16 to 25 CBM	Per Unit	48.36	39.28	48.36	39.28
	Vehicle above 25 CBM	Per Unit	214.02	173.91	214.02	117.27
	Vehicles up to 40 CBM	Per Unit	334.06	273.02	334.06	273.02
Average	**Harbour Dues = $86.34 = ₦116,990.7**					

Source: NPA Simplified Annual Tariff

Table 12: Cargo Dues

Area	**Cargo Type**	**Unit/Tonnage**	**Foreign**		**TWA/Coastal**	
			Import (USD)	**Export (USD**	**Import(USD)**	**Export (USD)**
NPA Area (Cargo Dues)	General Cargo	Per Ton	0.01	6.79	6.33	5.52
	Liquid Bulk	Per Ton	6.79	3.43	2.99	2.99
	Dry Bulk	Per Ton	6.79	4.90	4.90	4.90
	Container 20 FT Empty	Per Unit	21.85	18.40	18.40	18.40
	Container 20 FT Laden	Per Unit	215.05	138.00	138.00	138.00
	Container 40 FT Empty	Per Unit	35.65	32.20	35.65	32.20
	Container 40 FT Laden	Per Unit	340.40	230.00	230.00	230.00
	Vehicle Up to 15 CBM	Per Unit	50.60	43.70	41.40	41.40
	Vehicle 16 to 25 CBM	Per Unit	83.95	70.15	70.15	70.15
	Vehicle above 25 CBM	Per Unit	281.75	238.05	238.05	355.05
	Vehicles up to 40 CBM	Per Unit	474.95	399.05	399.05	399.05
Note: The components of Cargo Dues is made up of Harbour Dues, Stevedoring Charges and Environmental Protection Levy						
	General Cargo	Per Ton	5.52	4.72	4.37	4.37
	Dry Bulk	Per Ton	5.06	3.76	3.34	2.96
	Container 20 FT Empty	Per Ton	9.20	9.20	9.20	9.20
	Container 20 FT Laden	Per Unit	123.05	94.30	94.30	94.30
	Container 40 FT Empty	Per Unit	13.80	13.80	13.80	13.80
	Container 40 FT Laden	Per Unit	232.30	174.0	132.50	132.25
Appropriated Area (Cargo Dues)	Vehicle Up to 15 CBM	Per Unit	41.40	33.70	31.40	31.40
	Vehicle 16 to 25 CBM	Per Unit	65.55	53.25	53.25	53.25
	Vehicle above 25 CBM	Per Unit	236.90	192.51	192.51	192.51

	Vehicles up to 40 CBM	Per Unit	388.70	315.79	315.79	315.79
Vehicles above 120 CBM to be treated as General Cargo using tonnage or CBM , whichever one is higher						
	General Cargo	Per Ton	4.38	4.38	4.38	4.38
	Container 20 FT Empty	Per Ton	4.60	4.60	4.60	4.60
	Container 20 FT Laden	Per Ton	14.95	14.95	14.95	14.95
	Container 40 FT Empty	Per Unit	8.05	8.05	8.05	8.05
	Container 40 FT Laden	Per Unit	21.85	21.85	21.85	21.85
	Vehicle Up to 15 CBM	Per Unit	3.25	2.65	3.25	2.63
Midstream Discharge (Cargo Dues)	Vehicle 16 to 25 CBM	Per Unit	5.75	4.72	5.75	4.60
	Vehicle above 25 CBM	Per Unit	9.20	8.05	9.20	8.05
	Vehicles up to 40 CBM	Per Unit	20.70	17.25	20.70	17.25
Average	**Cargo Dues = $67.10 = ₦ 90,920.5**					

Source: NPA Simplified Annual Tariff

The representative coefficient for Cargo Dues was derived using the arithmetic mean for all valid tariff entries across NPA Area, Appropriated Area, and Midstream Discharge categories. A total of 120

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