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# Comparative Analysis of Nigerian Ports Operational Performance and their Effects on Nigerian Economy

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## Abstract

Nigeria's seaports' operational efficiency is vital to the nation's economic growth, especially when considering maritime GDP. The economic potential of Nigerian ports has been severely limited by inefficiencies, such as delays, traffic, and poor infrastructure, which have had a profound impact on industries that depend on imported goods. Comparative analysis of Nigerian seaports' operational performance and its effect on the country's maritime GDP is the goal of this study. The study uses Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), and Multiple Linear Regression to analyze secondary data on seaport operational performance from 2011 to 2023 taken from the Abstract and Statistics Department of the Nigerian Ports Authority and Maritime GDP data from the Central Bank of Nigeria (CBN) website. Warri Seaport is the most efficient seaport, surpassing Onne, Apapa, and Tincan Island seaports, according to the Decision-Making Units' (DMUs') efficiency summary output for 2011–2023. Warri has the highest efficiency percentage (21.15%), followed by Apapa (19.23%), Onne (17.39%), and Tincan Island (15.38%). According to the study, there is a substantial correlation between seaport operations and GDP, with important indicators like ship traffic and cargo throughput accounting for 88.7% of the variation in economic output. Even though they had detrimental effects, variables like waiting time and berth occupancy were not statistically significant. The study concludes that bolstering Nigeria's maritime economy requires better port operations. To improve overall port efficiency and economic growth, it is advised that significant investments be made in port infrastructure, technology, and workforce development. These investments should be combined with expedited customs procedures and the development of strategic international partnerships.

**Keywords:** Operational performance, Comparative analysis, Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Nigerian Seaports

## INTRODUCTION

The comparative examination of operational dynamics within Nigerian ports elucidates substantial ramifications for the national economy, particularly concerning efficiency, revenue generation, and infrastructural advancement. The efficacy of port operations is of paramount importance, as it exerts a direct impact on revenue generation and economic growth, with empirical research suggesting a positive correlation between enhanced operational efficiency and economic performance (Edih *et al.*, 2023). For example, the gross registered tonnage of the Apapa Seaport plays a pivotal role in contributing to Nigeria's GDP, thereby underscoring the significance of cargo throughput and maritime traffic (Omoke *et al.*, 2017). Moreover, the processes of privatization and concession of ports have engendered marked enhancements in various operational metrics, including berth occupancy and turnaround times, which are vital for improving service delivery and mitigating congestion (Dere *et al.*, 2021; Ndikom, 2012). Nonetheless, despite these advancements, certain scholarly investigations suggest that the overall efficiency of seaports may exhibit an inverse relationship with economic growth, indicating the necessity for further investments in technology and infrastructure to optimize performance and engender favorable economic outcomes (Maduechesi *et al.*, 2024). Consequently, although reforms have achieved notable progress, persistent challenges require sustained attention to the enhancement of port operations in order to fully exploit their economic potential.

This study therefore, examine the comparative analysis of Nigerian ports operational performance and their effects on Nigerian economy, seeks to explore and evaluate the operational performance of Nigerian seaports and its implications for the nation's economy, particularly the maritime GDP.
The specific objectives of the study are:

1. To determine the operational efficiency of Nigerian seaports.
2. To compare the efficiency of selected Nigerian seaports.
3. To analyze the effects of Nigerian seaport operational performance on the national economy, particularly the maritime sector's contribution to GDP.

By achieving these objectives, the research aim to provide valuable insights into the efficiency of Nigerian ports in contributing to national economic growth and identify areas that require improvement for enhanced performance and economic outcomes.

## LITERATURE REVIEW

### Port Operations

Port operations encompass a diverse array of activities and technologies that are strategically designed to enhance efficiency and performance within the domain of maritime logistics. The incorporation of sophisticated technologies, exemplified by modular multilevel converters (MMC), is instrumental in the optimization of port operations. For example, the nonagonal MMC, functioning as a soft open point (SOP) within distribution networks, can be modified to operate effectively under port reduction conditions by transitioning to a hexagonal MMC topology, thus preserving efficiency without necessitating additional hardware (Liu *et al.*, 2023).

Additionally, the role of artificial intelligence (AI) is pivotal in augmenting the efficiency of port operations by refining the precision of predictions pertaining to ship turnaround times and potential delays. Moreover, economic variables such as exchange rates and treasury bills exert a significant influence on maritime performance, indicating that the implementation of stable macroeconomic policies is imperative for sustaining operational efficiency (Irejeh *et al.*, 2023).

### Nigeria Economy

The influence of seaports on the Nigerian economy is intricate, involving aspects such as operational efficiency, trade dynamics, and revenue generation. Empirical studies suggest that the efficiency of seaports exhibits an inverse correlation with economic growth, indicating that notwithstanding various reforms, persistent operational inefficiencies continue to obstruct favorable economic outcomes (Maduechesi *et al.*, 2024). Moreover, the maritime sector's dependence on imports, in conjunction with fluctuations in exchange rates, exerts a considerable impact on the Gross Domestic Product (GDP), suggesting that a trade system heavily reliant on imports may not sustain long-term economic growth (Adenigbo *et* *al.*, 2023). Additionally, elevated logistics costs and insufficient infrastructure serve as impediments to international trade, underscoring the necessity for institutional enhancements aimed at improving the efficiency of seaborne trade (Salawu & Ghadiri, 2022). The efficacy of port operations is paramount for revenue generation, which consequently influences national development, thereby underscoring the critical role of advanced technologies and infrastructure investment (Edih *et al.*, 2023; Osadume, 2020). In summary, tackling these challenges is essential for optimizing the role of seaports as catalysts for economic growth within Nigeria.

**Empirical Review**

Nigerian seaports play a vital role in the nation's economic development, especially in industries like construction that depend heavily on imports, so their operational performance has attracted a lot of attention. Numerous studies that have evaluated different aspects of port efficiency have found that, despite advancements, there are still major obstacles to overcome, especially when it comes to operational inefficiencies that impede economic expansion.

An extensive study of the Apapa Seaport, one of Nigeria's busiest ports, and its effects on the country's economy was carried out by Omoke *et al.* (2017). They discovered that the economy was significantly harmed by Apapa's inefficiencies, which included poor cargo handling, traffic, and delays. Despite its strategic significance, the study found that Apapa Seaport had ongoing operational bottlenecks that impeded the flow of goods and increased costs for companies, especially those in industries that depended on imported materials. The authors contend that this inefficiency restricts the port's ability to make a significant contribution to Nigeria's GDP, especially in industries like construction that depend on prompt product deliveries.

The Calabar Free Port was also included in this assessment by Nwaogbe *et al.* (2020), who evaluated both its operational effectiveness and wider economic ramifications. According to their research, the Calabar port, like Apapa, had a number of operational issues, such as poor infrastructure, a lack of facilities for handling cargo, and ineffective bureaucracy. They maintained that these elements had a direct effect on port productivity, which raised operating costs and hampered economic growth, especially in sectors of the economy that depended on trade. They came to the conclusion that by increasing the productivity of industries linked to trade, expanding the operational capacity of ports like Calabar could have a major positive impact on the country's economic performance.

The operational performance of two ports in eastern Nigeria, Rivers and Delta Ports, was compared in a more recent study by Nwaogbe *et al.* (2023). According to their research, Rivers Port performs better than Delta Port in terms of personnel efficiency and cargo throughput, even though both ports deal with similar operational issues like traffic and processing delays. According to the study, these variations in port performance are significant because they have a direct impact on Nigerian ports' competitiveness and ability to contribute to national economic metrics like GDP. By contrasting these two ports, the authors brought attention to the differences in port efficiency between Nigeria's various regions and demonstrated how these differences can have a substantial impact on sectoral GDP contributions and economic output.

These conclusions are corroborated by research by Gbolahan *et al.* (2022) and Dere and Ojekunle (2025), which connects operational inefficiencies at Nigerian seaports to negative economic outcomes, especially for the construction industry. In their study of the connection between port performance and the GDP contribution of the construction industry in Nigeria, Dere and Ojekunle (2025) pointed out that inefficiencies like lengthy turnaround times at important ports like Apapa raise the price of building materials, which worsens the performance of the industry.

Additionally, there has been a lot of discussion about the privatisation of Nigerian ports. Ndikom and Obed (2013) evaluated the privatisation policy's effect on port productivity critically. Their analysis acknowledged some progress but pointed out that the privatisation process had not resulted in a thorough redesign of operational procedures and infrastructure, indicating that additional funding is required to produce long-lasting gains. This supports the conclusions of Nwaogbe *et al.* (2020), who contended that addressing ingrained inefficiencies in port operations through privatisation alone is insufficient.

Although Nigerian ports have experienced some improvements, overall productivity still falls short of international standards, mainly because of insufficient infrastructure, antiquated technology, and ineffective cargo handling procedures, according to empirical data on the productivity of Nigerian seaports presented by Gbolahan *et al.* (2022). They emphasised the differences in performance between smaller ports and larger ones, such as Apapa and Tin Can Island. The report also underlined that in order for Nigerian ports to realise their full economic potential, inefficiencies must be fixed throughout the country.

A number of Nigerian researchers have highlighted the vital role that transport and logistics play in improving port operations, which is consistent with international studies like those conducted by Rodrigue and Notteboom (2011) that highlight the significance of hinterland connectivity and logistics systems in boosting port efficiency. According to Nwaogbe *et al.* (2020), while technological developments and better management techniques may increase port efficiency, Nigerian ports' infrastructural difficulties and absence of integrated logistics systems continue to be major obstacles to optimal performance.

## Research Gap

Even though a lot of work has been done to assess the performance of Nigerian ports individually, there is still a significant research gap regarding the relative efficiency of Nigerian seaports and their combined economic impact. Previous research has mostly concentrated on particular ports, such as Apapa or Calabar, and frequently looks at their operational performance separately. Few studies, nevertheless, have conducted a thorough comparative analysis of several ports and their combined effects on Nigeria's economy as a whole, especially with regard to sectoral GDP contributions. It is challenging to evaluate how operational inefficiencies at various ports may collectively impede national economic growth due to the dearth of such studies. This research gap presents a chance to compare the effectiveness of Nigerian seaports (with a focus on Apapa, Tincan, Onne and Warri, from 2011 to 2023) and investigate the ways in which these differences in performance affect the nation's overall economic output (maritime GDP). Policymakers and port managers would benefit greatly from such an analysis in order to address the operational issues that still impede Nigeria's economic growth.

## METHODS

The study uses secondary data on ports operational variable (Cargo throughputs, berth occupancy, personnel, vessel traffic, vehicle traffic, gross registered tonnage, dwell time and turnaround time) and gross domestic product (GDP of maritime transport), the data were gotten from Nigerian Ports Authority from 2011 to 2023 and Central Bank of Nigeria website (real GDP in billion from 2011-2023). The study combines parametric and non-parametric techniques (Data Envelopment Analysis (DEAP 2.1), Stochastic Frontier Analysis (Frontier 4.1), and Multiple Regression Analysis (SPSS 23)). Descriptive analysis which involves the use of table were used to present the results.

## RESULTS AND DISCUSSION

### The Characteristics of Nigerian Seaports (Apapa, TinCan Island, Onne, and Warri) from 2011 to 2023

From the Table 1, 2, 3 and 4, reveals the output and inputs variables for the respective decision making units (seaports) under study from the year 2011 to 2023 (13 years). The output (y) is the cargo throughputs and the inputs of the four DMU's includes: personnel, ship traffic, vehicle traffic, gross registered tonnage, berth occupancy, vessel turnaround time, and dwell/waiting time of vessel.

### Descriptive Statistics for the DMU's sample

The Table 5 reveals the summary of the descriptive statistics for the four (4) decision making units under study of 13years and the contextual variables or metrics used for the DEA (CRS and VRS model) analysis. Table 5 presents the descriptive statistics of the sampled DMUs, with a focus on some key performance measures.

Cargo throughput had a mean of 17,130,468.3 tons (SD = 7,857,718.84), further ranging from a minimum value of 5,197,773 tons to a maximum of 27,580,642 tons, which is quite a significant range regarding operational capacities. Personnel averaged 432.58 employees (SD = 137.93),

**Table 1:** Apapa Port Complex Characteristics

| Year | Cargo Throughput | Personnel | Turn Around Time | Berth Occupancy | Vessel Traffic | Gross Registered Tonnage | Vehicle Traffic | Waiting Time |
|---|---|---|---|---|---|---|---|---|
| 2011 | 22308353 | 664 | 7.59 | 64.14 | 1594 | 32869251 | 3537 | 2.57 |
| 2012 | 19957705 | 610 | 7.96 | 65.25 | 1445 | 32072798 | 17121 | 2.95 |
| 2013 | 20344118 | 686 | 5.31 | 56.9 | 1510 | 34189172 | 14397 | 1.37 |
| 2014 | 20645269 | 656 | 3.91 | 42.4 | 1503 | 37041879 | 9611 | 1.46 |
| 2015 | 20250771 | 603 | 3.8 | 69.7 | 1410 | 36290502 | 6955 | 1.28 |
| 2016 | 18541041 | 573 | 4.7 | 55.5 | 1154 | 33612421 | 346 | 0.9 |
| 2017 | 19099690 | 578 | 5.1 | 55.76 | 1194 | 31614347 | 507 | 5.1 |
| 2018 | 20010677 | 637 | 6.15 | 52.96 | 1100 | 31949154 | 685 | 0.82 |
| 2019 | 21161156 | 644 | 5.87 | 44.8 | 1034 | 29446754 | 1663 | 0.17 |
| 2020 | 20285094 | 559 | 6.81 | 52.08 | 986 | 24607375 | 2256 | 0.23 |
| 2021 | 21238348 | 559 | 6.19 | 50.82 | 1080 | 26893200 | 9315 | 0.29 |
| 2022 | 21387008 | 588 | 6.33 | 52.48 | 1095 | 29259853 | 18873 | 0.23 |
| 2023 | 18644936 | 566 | 5.05 | 39.66 | 1061 | 32429896 | 6698 | 0.15 |

**Source:** Nigerian Ports Authority, Corporate and Strategic Planning Division (2024)

**Table 2:** Tincan Island Port Complex Characteristics

| Year | Cargo Throughput | Personnel | Turn Around Time | Berth Occupancy | Vessel Traffic | Gross Registered Tonnage | Vehicle Traffic | Waiting time |
|---|---|---|---|---|---|---|---|---|
| 2011 | 16230591 | 537 | 4.97 | 69 | 1628 | 32702604 | 243454 | 1.01 |
| 2012 | 15268897 | 525 | 5.04 | 69.91 | 1508 | 32636886 | 251322 | 1.51 |
| 2013 | 16134118 | 472 | 4.5 | 65.9 | 1615 | 40096754 | 265209 | 1.37 |
| 2014 | 17500804 | 453 | 3.95 | 71.3 | 1692 | 47231548 | 237904 | 1.21 |
| 2015 | 16407133 | 435 | 4.1 | 54.1 | 1656 | 45864565 | 124841 | 1.58 |
| 2016 | 15648919 | 397 | 3.5 | 46.4 | 1307 | 45229402 | 104571 | 1 |
| 2017 | 15464385 | 392 | 4 | 43.9 | 1559 | 40694756 | 180753 | 4 |
| 2018 | 15057472 | 389 | 3.93 | 36.8 | 1103 | 36083990 | 219293 | 0.93 |
| 2019 | 17035589 | 400 | 3.98 | 52.17 | 1311 | 44231391 | 275448 | 0.55 |
| 2020 | 15529360 | 382 | 5.8 | 61.17 | 1127 | 35928785 | 274428 | 2.23 |
| 2021 | 16779276 | 307 | 5.68 | 55.76 | 1128 | 34994941 | 331415 | 1.68 |
| 2022 | 15013306 | 327 | 4.62 | 50.89 | 1085 | 34156767 | 175677 | 1.68 |
| 2023 | 12915998 | 398 | 4.82 | 36.07 | 998 | 33153896 | 125595 | 1.79 |

**Source:** Nigerian Ports Authority, Corporate and Strategic Planning Division (2024)

**Table 3:** Onne Port Characteristics

| Year | Cargo Throughput | Personnel | Turn Around Time | Berth Occupancy | Vessel Traffic | Gross Registered Tonnage | Vehicle Traffic | Waiting time |
|---|---|---|---|---|---|---|---|---|
| 2011 | 26529884 | 207 | 4.05 | 31.61 | 885 | 42735452 | 272 | 0.22 |
| 2012 | 27580642 | 205 | 3.43 | 31.09 | 885 | 42910262 | 285 | 0.06 |
| 2013 | 24773387 | 269 | 4.12 | 26.7 | 823 | 38612995 | 260 | 0.11 |
| 2014 | 27968861 | 258 | 4.56 | 44.2 | 418 | 8926192 | 106 | 0.32 |
| 2015 | 26314828 | 247 | 3.6 | 36.1 | 339 | 7296978 | 196 | 0.24 |
| 2016 | 23434241 | 250 | 2.8 | 28.5 | 291 | 7564109 | 272 | 0.3 |
| 2017 | 26049222 | 284 | 5.2 | 18.4 | 276 | 7396251 | 3 | 2.5 |
| 2018 | 26528748 | 278 | 3.05 | 19.8 | 663 | 42296506 | 0 | 0.55 |
| 2019 | 27399617 | 284 | 4.75 | 26.54 | 726 | 43749724 | 0 | 1.15 |
| 2020 | 27536006 | 288 | 3.17 | 24.95 | 696 | 42707933 | 0 | 0.63 |
| 2021 | 25088809 | 288 | 3.9 | 30.37 | 685 | 39125200 | 0 | 0.74 |
| 2022 | 22294590 | 273 | 2.95 | 18.2 | 658 | 35534732 | 0 | 0.52 |
| 2023 | 21314440 | 274 | 2.75 | 18.17 | 654 | 33508527 | 0 | 0.64 |

**Source:** Nigerian Ports Authority, Corporate and Strategic Planning Division (2024)

**Table 4:** Warri Seaport Characteristics

| Year | Cargo Throughput | Personnel | Turn Around Time | Berth Occupancy | Vessel Traffic | Gross Registered Tonnage | Vehicle Traffic | Waiting time |
|---|---|---|---|---|---|---|---|---|
| 2011 | 7908566 | 411 | 7 | 31.75 | 362 | 2968067 | 323 | 1.2 |
| 2012 | 6987533 | 383 | 6.17 | 12.12 | 615 | 5597515 | 658 | 1.13 |
| 2013 | 10361746 | 414 | 5.41 | 13.3 | 609 | 8687160 | 360 | 0.99 |
| 2014 | 10199169 | 399 | 5.6 | 12.3 | 603 | 7860797 | 311 | 1.33 |
| 2015 | 7829826 | 385 | 5 | 13.1 | 528 | 5822393 | 2 | 0.99 |
| 2016 | 6836616 | 362 | 3.5 | 8.5 | 438 | 6120242 | 0 | 7 |
| 2017 | 5197773 | 365 | 3.5 | 13 | 448 | 6086833 | 0 | 3.5 |
| 2018 | 7165907 | 377 | 3.56 | 15.81 | 503 | 7454352 | 32 | 0.31 |
| 2019 | 8972879 | 357 | 4.08 | 18.27 | 690 | 12405182 | 8 | 0.2 |
| 2020 | 8311034 | 307 | 4.03 | 16.5 | 653 | 11995212 | 15 | 0.7 |
| 2021 | 9065078 | 307 | 3.83 | 20.6 | 670 | 13487836 | 25 | 1.08 |
| 2022 | 9112478 | 311 | 4.09 | 18.42 | 598 | 11247162 | 85 | 0.67 |
| 2023 | 9312508 | 311 | 3.1 | 14.48 | 543 | 11824845 | 70 | 0.11 |

**Source:** Nigerian Ports Authority, Corporate and Strategic Planning Division (2024)

**Table 5:** Summary of Descriptive Statistics for the DMU's sample

| Metric | Count | Mean | Std Dev | Min | 25% | 50% | 75% | Max |
|---|---|---|---|---|---|---|---|---|
| Cargo Throughput | 52 | 17130468.3 | 7857718.84 | 5197773 | 12916000 | 19099700 | 21238400 | 27580642 |
| Personnel | 52 | 432.58 | 137.93 | 205 | 307 | 385 | 566 | 686 |
| Turn Around Time | 52 | 4.56 | 1.47 | 2.75 | 3.9 | 4.56 | 5.68 | 7.96 |
| Berth Occupancy | 52 | 40.97 | 16.94 | 8.5 | 28.5 | 46.4 | 56.9 | 71.3 |
| Vessel Traffic | 52 | 893.56 | 419.74 | 276 | 654 | 1103 | 1307 | 1692 |
| Gross Registered Tonnage | 52 | 20780292.7 | 12535498.3 | 2968067 | 7396251 | 31949154 | 40694756 | 47231548 |
| Vehicle Traffic | 52 | 38166.65 | 75127.97 | 0 | 3 | 331 | 104571 | 331415 |
| Waiting Time | 52 | 1.27 | 1.32 | 0.06 | 0.22 | 0.93 | 1.58 | 7 |

**Source:** Authors computation (2024)

ranging from 205 to a maximum of 686, reflecting variability in workforce size among DMUs.

The mean turnaround time, an important indicator of efficiency, was 4.56 days with a standard deviation of 1.47 days, while the minimum and maximum were 2.75 and 7.96 days, respectively, reflecting a fair deal of variability around the operational timing. The average berth occupancy was 40.97% with a standard deviation of 16.94, while the minimum and maximum were 8.5% and 71.3%, respectively, reflecting a range of utilization levels of berth facilities.

The sample mean for vessel traffic was 893.56 vessels, SD = 419.74, ranging from 276 vessels to 1,692 vessels. Gross registered tonnage also varied greatly with an average of 20,780,292.7 tons, SD = 12,535,498.3, ranging from 2,968,067 tons to 47,231,548 tons.

Vehicles traffic are highly positively-skewed with an average of 38,166.65 vehicles with a standard deviation of 75,127.97 and minimum and maximum 0 and 331,415 vehicles, respectively, indicating that there are calm periods in the number of vehicle flow for some DMUs. And the last one refers to waiting time, which has an average of 1.27 days with a standard deviation of 1.32 days, ranging between 0.06 and 7 days, thereby showing large variation in delays of the ports.

Above descriptive statistics give a general view of heterogeneity of DMUs respecting the value of throughput, resources, efficiency, and traffic metrics, emphasizing several factors in relation to operational conditions of the sample.

**Correlation Matrix Analysis**

The correlation analysis indicates the positive significant relationships between the output (cargo throughputs) and inputs metrics (personnel, berth occupancy, vessel turnaround time, ship traffic, vehicle traffic, and dwell time) which are justified to be included in the model. The correlation analysis for the selected four (4) Nigerian seaports shows various significant relationships between the output and the inputs metrics used for the DEA (CRS and VRS model) analysis.

**Table 6:** Correlation Matrix of the DMUs Variables

| Variables | Cargo Throughput | Personnel | Turn Around Time | Berth Occupancy | Vessel Traffic | Gross Registered Tonnage | Vehicle Traffic | Waiting Time |
|---|---|---|---|---|---|---|---|---|
| Cargo Throughput | 1 | | | | | | | |
| Personnel | 0.79 | 1 | | | | | | |
| Turn Around Time | 0.25 | 0.41 | 1 | | | | | |
| Berth Occupancy | 0.48 | 0.38 | 0.31 | 1 | | | | |
| Vessel Traffic | 0.93 | 0.78 | 0.26 | 0.54 | 1 | | | |
| Gross Registered Tonnage | 0.95 | 0.74 | 0.23 | 0.44 | 0.88 | 1 | | |
| Vehicle Traffic | 0.59 | 0.36 | 0.13 | 0.24 | 0.49 | 0.56 | 1 | |
| Waiting Time | -0.06 | -0.2 | 0.21 | -0.08 | -0.12 | -0.02 | 0.02 | 1 |

**Source:** Authors computation (2024)

Table 6 shows that the correlation analysis of Cargo Throughput (output) and key input variables highlighted several significant relationships, shedding light on factors influencing port performance. Personnel exhibited a strong positive correlation with Cargo Throughput (r = .79, $p$ < .001), suggesting that increasing personnel enhances cargo handling capacity. Similar trends were observed with Vessel Traffic (r = .93, $p$ < .001) and Gross Registered Tonnage (r = .95, $p$ < .001), indicating their critical roles in port activity. Berth Occupancy showed a moderate positive correlation (r = .48, p = .001), implying that optimal berth utilization can support higher throughput.

Turnaround Time showed a weak positive correlation with Cargo Throughput (r = .25, $p$ = .07), which was not statistically significant, suggesting independence between the variables, possibly due to variations in operational efficiency. Vehicle Traffic, representing land-side goods movement, was moderately correlated with throughput (r = .59, $p$ < .001), reflecting the connection between maritime and hinterland activities.

Conversely, Waiting Time had a negligible and non-significant correlation (r = -.06, $p$ = .65), suggesting that increased cargo handling may not necessarily cause delays.

These findings align with prior research on port efficiency, which underscores maritime traffic and tonnage as significant predictors of throughput, while factors like turnaround and waiting times are influenced by management practices and infrastructure (Cullinane *et al.*, 2006; UNCTAD, 2021). Ports aiming to improve throughput should focus on optimizing vessel traffic, tonnage handling, and staffing levels while addressing operational efficiency metrics such as turnaround and waiting times.

**Data Envelopment Analysis (CRS and VRS) of Nigerian Seaports Productivity and Efficiency**

The Data Envelopment Analysis (DEA) efficiency scores for Apapa, TinCan Island, Onne, and Warri seaports illustrate substantial differences in technical, scale, and overall operational efficiency during the study period. These variations reflect each port's strengths and challenges, with broader implications for Nigeria's trade and economic activities.

From the efficiency summary output of the decision making units for the time period of 2011 to 2023. The results in Table 7 show that Warri seaport is the most efficient as compared to Onne, Apapa and Tincan Island seaports. In the aggregate percentage of efficiency, Warri accounts for 21.15% (11), while Apapa account for 19.23% (10), Onne port has a score of 17.39% (9), and Tincan Island port has the least efficiency score and percentage of 15.38% (8) of the overall 76.9% (40) efficiency percentage and score of the 4 decision making units.

**Table 7:** Comparative Efficiency Summary of the DMUs

| DMU | Efficiency score | Inefficiency score | Efficiency percentage | Inefficiency percentage | Total percentage | Rank |
|---|---|---|---|---|---|---|
| Apapa | 10 | 3 | 19.23 | 5.77 | 25 | 2 |
| TinCan Island | 8 | 5 | 15.38 | 9.61 | 25 | 4 |
| Onne | 9 | 4 | 17.39 | 7.61 | 25 | 3 |
| Warri | 11 | 2 | 21.15 | 3.85 | 25 | 1 |
| Total | 40 | 12 | 76.9 | 23.08 | 100 | |

**Source:** Authors computation, (2024)

Table 8 shows that Apapa port has consistently achieved high efficiency scores since 2014, with both constant returns to scale (CRS) and variable returns to scale (VRS) models indicating perfect efficiency (1.000). Prior to 2014, efficiency fluctuated, evidenced by a CRS technical efficiency (CRSTE) of 0.933 in 2011, suggesting underutilization of resources. Scale efficiency dynamics reveal periods of both decreasing (DRS) and increasing returns to scale (IRS), pointing to inefficiencies caused by capacity mismatches. Barros and Athanassiou (2004) stress that achieving consistent CRS is critical for sustaining reliability and economic contributions. Similarly, Dere and Ojekunle (2025) advocate for targeted infrastructure improvements to address scale inefficiencies and maintain high performance at major ports like Apapa.

**Table 8:** Efficiency Summary of Apapa Seaport under Period of Study

| DMU Year | crste | vrste | Scale | Return of Scale | Rank |
|---|---|---|---|---|---|
| 2011 | 0.933 | 1.000 | 0.933 | Drs | 13 |
| 2012 | 0.861 | 0.916 | 0.940 | Irs | 12 |
| 2013 | 0.914 | 0.936 | 0.977 | Irs | 11 |
| 2014 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2015 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2016 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2017 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2018 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2019 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2020 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2021 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2022 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2023 | 1.000 | 1.000 | 1.000 | Crs | 1 |

**Source:** Authors computation (2024)

**Note:**

crste = technical efficiency from CRS DEA

vrste = technical efficiency from VRS DEA

Scale = scale efficiency = crste/vrste

Table 9 shows that TinCan Island port displays a trend of high efficiency, with perfect scores recorded for years such as 2011, 2014, and 2016–2023. However, CRSTE dropped to 0.952 in 2012 and 2020, reflecting resource allocation or operational challenges. During these years, the port alternated between IRS and DRS, indicating inconsistent capacity utilization. Such inefficiencies likely stem from congestion or infrastructure constraints, as noted by Cullinane *et al.* (2006), who highlight the negative impact of scale imbalances on port competitiveness. However, operational reforms, including decongestion initiatives, have improved efficiency in recent years, as observed by Gbolahan *et al.* (2022).

**Table 9:** Efficiency Summary of TinCan Island Seaport under Period of Study

| DMU Year | crste | vrste | Scale | Return of Scale | Rank |
|---|---|---|---|---|---|
| 2011 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2012 | 0.952 | 1.000 | 0.952 | Irs | 11 |
| 2013 | 0.947 | 0.948 | 0.999 | Irs | 9 |
| 2014 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2015 | 0.995 | 1.000 | 0.995 | Drs | 13 |
| 2016 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2017 | 0.980 | 0.981 | 0.999 | Drs | 12 |
| 2018 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2019 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2020 | 0.952 | 0.964 | 0.988 | Irs | 10 |
| 2021 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2022 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2023 | 1.000 | 1.000 | 1.000 | Crs | 1 |

**Source:** Authors computation (2024)

Onne port in Table 10 maintains a stable efficiency profile, with perfect CRS and VRS scores for most of the study period (2012–2020). Marginal inefficiencies observed in 2021 (CRSTE 0.994) and 2022 (CRSTE 0.989) correspond to IRS, indicating the need to scale operations to meet growing demand. Cheon *et al.* (2010) emphasize that maintaining optimal scale efficiency is essential for ports experiencing high growth potential. Dere *et al.* (2021) further highlight Onne port as an example of how effective scaling can mitigate inefficiencies and enhance competitiveness.

**Table 10:** Efficiency Summary of Onne Seaport under Period of Study

| DMU Year | crste | Vrste | Scale | Return of Scale | rank |
|---|---|---|---|---|---|
| 2011 | 0.967 | 1.000 | 0.967 | Irs | 13 |
| 2012 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2013 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2014 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2015 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2016 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2017 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2018 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2019 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2020 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2021 | 0.994 | 1.000 | 0.994 | irs | 11 |
| 2022 | 0.989 | 1.000 | 0.989 | irs | 12 |
| 2023 | 0.996 | 1.000 | 0.996 | irs | 10 |

**Source:** Authors computation (2024)

Table 11 revealed that Warri port achieves perfect efficiency scores in most years, meeting both CRS and VRS criteria. However, inefficiencies in 2012 (CRSTE 0.900) and 2022 (CRSTE 0.994) are tied to IRS, reflecting underutilization due to reduced cargo throughput or infrastructure constraints. Smaller regional ports like Warri often face efficiency challenges during fluctuating trade volumes, as observed by Notteboom and Rodrigue (2005). Despite these challenges, Gbolahan *et al.* (2022) note that Warri's high efficiency levels demonstrate its untapped potential to relieve pressure on larger ports like Apapa.

**Table 11:** Efficiency Summary of Warri Seaport under Period of Study

| DMU Year | Crste | vrste | Scale | Return of Scale | Rank |
|---|---|---|---|---|---|
| 2011 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2012 | 0.900 | 1.000 | 0.900 | Irs | 13 |
| 2013 | 1.000 | 1.000 | 1.000 | Crs | 1 |
| 2014 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2015 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2016 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2017 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2018 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2019 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2020 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2021 | 1.000 | 1.000 | 1.000 | crs | 1 |
| 2022 | 0.994 | 1.000 | 0.994 | irs | 12 |
| 2023 | 1.000 | 1.000 | 1.000 | crs | 1 |

**Source:** Authors computation (2024)

**Port Comparative Insights: Efficiency Trends**
Apapa and TinCan Island ports initially struggled with inefficiencies but achieved consistent CRS efficiency post-2014, reflecting the benefits of operational reforms. In contrast, Onne and Warri ports maintained higher efficiency throughout, reflecting better resource utilization.

i. **Scale Efficiency/Dynamics:** Scale efficiency metrics indicate that Apapa and TinCan Island experienced oscillations between IRS and DRS before reaching CRS, while Onne and Warri more consistently operated near optimal scale. These findings align with UNCTAD (2017), which highlights the adaptability of ports with diverse service capabilities.
ii. **Economic Implications:** Inefficiencies during IRS periods likely limited throughput and increased operational costs, especially for Apapa and TinCan Island, which are critical for Nigeria's trade logistics. This aligns with World Bank (2020) findings on inefficiencies in Nigerian trade logistics systems.
iii. **Policy Implications:** Continued investment in port infrastructure, particularly at Apapa and TinCan Island, is essential to sustain efficiency gains. Expanding operational capacity at Onne and Warri can alleviate congestion and optimize national trade flow.

The DEA findings emphasize the importance of efficiency in port operations for economic growth. While Apapa and TinCan Island have made significant strides in improving efficiency, the consistent performance of Onne and Warri highlights the potential for a decentralized approach to enhance national trade logistics. These results support the conclusions of Simanjuntak *et al.* (2024), Dere *et al.* (2021) and Gbolahan *et al.* (2022), underscoring the need to address inefficiencies and maximize the operational potential of Nigeria's ports

**The Stochastic Frontier Production**
The FRONT 4.1 is applied to determine the technical efficiency of the seaports in Nigeria. The study uses FRONT 4.1 with the trans-log production function for the analysis of the technical efficiency of the DMU's.

Cobb-Douglas and Trans-log functional forms for stochastic production function forms are tested based on maximum likelihood method by applying FRONTIER package version 4.1. The following, Equation (4), is the stochastic production function to be tested

Cargo Throughput$_i$ = *f*(Personnel$_i$, Ship Traffic$_i$, Vehicle Traffic$_i$, Berth Occupancy$_i$, Gross Registered Tonnage$_i$, Dwell Time$_i$, Ship Turnaround Time$_i$; β)+$v_i$−$u_i$

Where:

Cargo Throughput ($Y$): The output for observation $i$ (dependent variable)

*f(·)*: The production function that describes the relationship between inputs and output. A commonly used function is the Cobb-Douglas production function

$$f(x:\beta) = \beta_o \prod_{j=1}^{n} x_{ij}^{\beta_j}$$

*equation 1*

Here, $X_{IJ}$ represents the $J^{th}$ input for the $i^{th}$ observation, and $\beta_j$ are the parameters to estimate.

- Inputs (independent variables):
- Personnel ($x_1$)
- Ship Traffic ($x_2$)
- Vehicle Traffic ($x_3$)
- Berth Occupancy ($x_4$)
- Gross Registered Tonnage ($x_5$)
- Dwell Time ($x_6$).
- Ship Turnaround Time ($x_7$)
- $v_i$: The symmetric error term capturing random noise (external shocks).
- $u_i$: The non-negative inefficiency term representing deviation from the efficient frontier.
- Post-estimation, to be obtain:
- Maximum likelihood estimation (MLE) is use to estimate the parameters (β, $\sigma v^2$, $\sigma u^2$) and decompose the error
- Efficiency scores ($1-u_i$) for each observation.
- Coefficient estimates ($\beta_j$ ) indicating the impact of each input on the output.

Model diagnostics, including log-likelihood, LR test, and inefficiency distributions.

The Maximum Likelihood Estimates (MLE) derived from Stochastic Frontier Analysis (SFA) provide insights into the operational efficiencies of four Nigerian ports; Apapa, TinCan Island, Onne, and Warri. The findings reveal varied productivity levels and key factors affecting each port's performance, aligning with numerous studies on port efficiency and their impact on economic activity.

**Table 12:** Maximum Likelihood Estimates of the Stochastic Frontier Analysis of the Apapa Port

| Variables and Parameters | Coefficient | ML Estimates | |
|---|---|---|---|
| | | Standard-Error | t-Ratio |
| Constant | 19.7464 | 0.999 | 0.0019 |
| Personnel | 0.4474 | 0.944 | 0.4741 |
| Turnaround Time | 0.0033 | 0.366 | 0.0091 |
| Berth Occupancy | 0.0599 | 0.918 | 0.0654 |
| Ship Traffic | 0.2434 | 0.932 | 0.2611 |
| Vehicle Traffic | -0.4536 | 0.468 | -0.9693 |
| Gross Registered Tonnage | 0.0112 | 0.048 | 0.2339 |
| Waiting Time | -0.0180 | 0.124 | -0.1456 |
| Sigma squared | 0.0014 | 0.0016 | 0.8507 |
| Gamma | 1.0000 | 0.1889 | 5.2949 |
| LR test | 6.101 | | |
| Log likelihood function | 30.604 | | |

**** Significant at 1%; ** Significant at 5%, * Significant at 10%*

**Source:** Authors computation (2024)

**Table 13:** Maximum Likelihood Estimates of the Stochastic Frontier Analysis of the TinCan Island port

| **Variables and Parameters** | **Coefficient** | **ML Estimates** | |
|---|---|---|---|
| | | Standard-Error | t-ratio |
| Constant | 12.8127 | 1.000 | 12.8127 |
| Personnel | -0.3426 | 1.000 | -0.3425 |
| Turnaround Time | 0.0744 | 1.000 | 0.0744 |
| Berth Occupancy | 0.0643 | 1.000 | 0.0643 |
| Ship Traffic | 0.3617 | 1.000 | 0.3617 |
| Vehicle Traffic | 0.1258 | 1.000 | 0.1258 |
| Gross Registered Tonnage | 0.0566 | 1.000 | 0.0566 |
| Waiting Time | -0.0681 | 1.000 | -0.0681 |
| Sigma squared | 0.0005 | 1.000 | 0.0005 |
| Gamma | 0.9500 | 1.000 | 0.9500 |
| LR test | 1.7948 | | |
| Log likelihood function | 37.4915 | | |

*** Significant at 1%; ** Significant at 5%, * Significant at 10%.

**Source:** Authors computation (2024)

**Table 14:** Maximum Likelihood Estimates of the Stochastic Frontier Analysis of the Onne port

| **Variables and Parameters** | **Coefficient** | **ML Estimates** | |
|---|---|---|---|
| | | Standard-Error | t-ratio |
| Constant | 16.9060 | 1.2471 | 13.5562 |
| Personnel | -0.3855 | 0.1867 | -2.0637 |
| Turnaround Time | 0.3866 | 0.1117 | 3.4598 |
| Berth Occupancy | 0.2187 | 0.0722 | 3.0288 |
| Ship Traffic | -0.6348 | 0.2615 | -2.4274 |
| Vehicle Traffic | 0.3005 | 0.1290 | 0.2329 |
| Gross Registered Tonnage | -0.0314 | 0.0177 | -1.7714 |
| Waiting Time | -0.0932 | 0.0524 | -1.7772 |
| Sigma squared | 0.0020 | 0.0008 | 2.4342 |
| Gamma | 0.0002 | 0.1125 | 0.0019 |
| LR test | 1.541 | | |
| Log likelihood function | 21.9130 | | |

*** Significant at 1%; ** Significant at 5%, * Significant at 10%.

**Source:** Authors computation (2024)

**Table 15:** Maximum Likelihood Estimates of the Stochastic Frontier Analysis of the Warri seaport

| **Variables and Parameters** | **Coefficient** | **ML Estimates** | |
|---|---|---|---|
| | | Standard-Error | t-ratio |
| Constant | 3.8315 | 0.9943 | 3.8533 |
| Personnel | 0.2615 | 0.2169 | 1.2053 |
| Turnaround Time | 1.2738 | 0.3990 | 3.1923 |
| Berth Occupancy | -0.1740 | 0.1161 | -1.4989 |
| Ship Traffic | -1.6681 | 0.6343 | -2.6296 |
| Vehicle Traffic | 1.2418 | 0.3013 | 4.1216 |
| Gross Registered Tonnage | -0.0045 | 0.0119 | -0.3791 |
| Waiting Time | -0.0379 | 0.0253 | -1.5018 |
| Sigma squared | 0.0059 | 0.0027 | 2.1821 |
| Gamma | 1.0000 | 0.0038 | 26.3945 |
| LR test | 3.8527 | | |
| Log likelihood function | 22.4077 | | |

*** Significant at 1%; ** Significant at 5%, * Significant at 10%.

**Source:** Authors computation (2024)

The analysis of Maximum Likelihood Estimates (MLE) metrics including sigma squared ($\sigma^2$), gamma ($\gamma$), likelihood ratio (LR) test, and log-likelihood function offers valuable insights into the efficiency and reliability of Stochastic Frontier Analysis (SFA) models applied to Nigerian ports. These metrics reveal key details about the operational performance of Apapa, TinCan Island, Onne, and Warri ports.

Sigma squared ($\sigma^2$), representing the variance from random noise, shows relatively low values across the ports, indicating that random factors contribute minimally to overall variance. For example, in table 12 shows that Apapa port's $\sigma^2$ is 0.0014, reflecting minimal noise influence, while in table 15, Warri port's slightly higher $\sigma^2$ of 0.0059 indicates more random fluctuations. According to Aigner *et al.* (1977), lower $\sigma^2$ values enhance the SFA model's reliability, as they demonstrate that inefficiency, rather than randomness, primarily explains deviations from the production frontier.
Gamma ($\gamma$), which measures the proportion of variance attributable to inefficiency, highlights distinct patterns. In table 12 and 15 revealed that, Apapa and Warri ports both exhibit $\gamma$ values of 1.0000, meaning that nearly all performance deviations stem from inefficiencies, emphasizing a need for managerial and operational reforms. In table 13, TinCan Island port, with a $\gamma$ of 0.9500, shows similarly high inefficiency contributions, though slightly less pronounced. Table 14 in contrast, Onne port's exceptionally low $\gamma$ value of 0.0002 suggests that random noise, not inefficiency, drives its variance. As Battese and Coelli (1992) explain, low $\gamma$ values like Onne's indicate better control over inefficiencies compared to other ports.

The LR test evaluates the statistical significance of inefficiency effects in the model. In table 12, Apapa port has an LR value of 6.101, signaling moderate significance of inefficiency effects. Warri (3.8527) in table 15, and in table 13, TinCan Island (1.7948) ports show weaker significance, while in table 14, Onne port with an LR value of 1.541, suggests that inefficiencies are statistically less prominent. Coelli *et al.* (2005) highlight that higher LR values justify including inefficiency effects in the model, with Apapa's results underscoring its significant operational challenges.

The log-likelihood function, which measures the goodness-of-fit of the SFA model, indicates in table 13 that TinCan Island port has the best model fit, with a log-likelihood value of 37.4915. Apapa port in table 12 also shows a relatively strong fit with a value of 30.604. However, in table 14, Onne (21.9130), and Warri (22.4077) ports in table 15 exhibit lower values, suggesting less robust model performances. As Greene (2008) notes, higher log-likelihood values reflect a model's ability to capture the data accurately, reinforcing TinCan Island's potential for efficiency improvements.

Overall, the combined analysis of these metrics provides a nuanced understanding of the operational efficiencies of Nigerian ports. Apapa and Warri ports exhibit significant inefficiency contributions, as evidenced by their high $\gamma$ values and moderate LR scores, which call for targeted interventions. TinCan Island port, while also inefficient, benefits from a better-fitting model (high log-likelihood), suggesting opportunities for operational improvements. Onne port, characterized by low $\gamma$ and LR values alongside a moderate log-likelihood score, stands out as an outlier where random noise, rather than inefficiency, dominates performance deviations. These findings align with the broader academic discourse, as articulated by Coelli *et al.* (2005) and Greene (2008), emphasizing the value of these metrics in diagnosing inefficiencies and guiding operational enhancements.

**The relationship between Nigerian seaports operational performance and gross domestic product (maritime gross domestic product)**

The table above shows the gross domestic product (GDP) and characteristic of the Nigerian seaports over the years of study in trans-log. The descriptive summary of the Decision-Making Units (DMUs) variables offers insights into key statistics such as averages, variability, and range for each variable. For instance, the logarithmic GDP (LnGDP) reflects stability, with an average of 22.2212, low variability (SD = 0.1089), and values between 22.045 and 22.4225. Similarly, logarithmic consumption of total health products (LnCTHP) shows minimal variation (SD = 0.0634), averaging 18.0544, with a range of 17.9457 to 18.1504. Population (LnP), with an average of 5.8955 and variability akin to LnGDP (SD = 0.1088), spans from 5.7268 to 6.0259.

**Table 16:** Descriptive Summary of the DMUs variables

| Variable | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| LnGDP | 22.2212 | 0.1089 | 22.045 | 22.4225 |
| LnCTHP | 18.0544 | 0.0634 | 17.9457 | 18.1504 |
| LnP | 5.8955 | 0.1088 | 5.7268 | 6.0259 |
| LnTAT | 2.9275 | 0.1246 | 2.6741 | 3.1617 |
| LnBO | 5.0467 | 0.1415 | 4.6856 | 5.2807 |
| LnST | 8.2086 | 0.1092 | 8.0678 | 8.4244 |
| LnVT | 12.295 | 0.3121 | 11.5635 | 12.7389 |
| LnGRT | 18.5025 | 0.1278 | 18.2674 | 18.6818 |
| LnWT | 1.4319 | 0.5474 | 0.7275 | 2.7147 |

**Source:** Authors computation (2024)

On the other hand, total assets turnover (LnTAT) has slightly higher variability (SD = 0.1246), averaging 2.9275, and ranges from 2.6741 to 3.1617. Banking output (LnBO) shows moderate variability (SD = 0.1415), with an average of 5.0467 and a range from 4.6856 to 5.2807. Logarithmic statistics (LnST) are consistent, with an average of 8.2086, a standard deviation of 0.1092, and values ranging between 8.0678 and 8.4244.

Vehicle turnover (LnVT), however, exhibits greater variability (SD = 0.3121), averaging 12.295 and spanning a wide range from 11.5635 to 12.7389. Gross revenue turnover (LnGRT) maintains low variability (SD = 0.1278) and averages 18.5025, with values ranging from 18.2674 to 18.6818. Finally, workforce turnover (LnWT) displays the highest variability (SD = 0.5474), with a mean of 1.4319 and a broad range from 0.7275 to 2.7147.

These statistics collectively highlight varying degrees of stability and dispersion across the DMU variables, providing a detailed picture of their characteristics and interrelations. Knowledge of this descriptive statistic will be valuable in interpreting how operating variability might impact GDP outputs and what specific points should be addressed to improve port operations.

**Table 17:** Model Summary

| Model | R | R-Squared | Adjusted R-Squared | Std. Error of the Estimate |
|---|---|---|---|---|
| Regression | 0.942 | 0.887 | 0.829 | 0.064 |

**Source:** Authors Computation (2024)

Table 17, the model summary shows a very strong predictive relationship between the Nigerian seaport operational performance indicators and Gross Domestic Product. To this end, the multiple correlation coefficient R has been measured to be 0.942, showing the high level of association that characterizes the independent variables with regard to GDP (Cohen, 1988). Moreover, the coefficient of determination $R^2$=0.887 indicates that 88.7% of the variance in GDP is explained by the model, its explanatory power being considerable as confirmed by the value of $R^2$ (Field, 2018). Having adjusted for the number of predictors, the Adjusted $R^2$ value of 0.829 means that even accounting for Model complexity, the predictors all together possess substantial explanatory power (Tabachnick and Fidell, 2019). The standard error of the estimate is 0.064, which means that on average, the observed and predicted values of GDP differ by this amount.

**Table 18:** ANOVA Table

| Source | Sum of Squares | Df | Mean Square | F | Sig. (p-value) |
|---|---|---|---|---|---|
| Regression | 0.202 | 8 | 0.025 | 6.139 | 0.01 |
| Residual | 0.026 | 5 | 0.005 | | |
| Total | 0.228 | 13 | | | |

**Source:** Authors Computation (2024)

The Table 18 shows that the ANOVA result from the model provides evidence that regression is significantly predicting Gross Domestic Product based on the seaport operational performance selected indicators. The F-ratio is F (8,5)=6.139, which is statistically significant with a p-value of 0.010, therefore suggesting that taken together, these predictors explain variance in the GDP beyond what might be expected by chance. The result confirms our hypothesis that variables such as waiting time, vehicle traffic, and cargo throughput in Nigerian seaports are very significant in their impact on economic performance proxied by GDP. Using Tabachnick and Fidell (2019), if the F-statistic is significant at less than a 0.05 p-value, it means that the estimated regression model fits the data better than a no-predictor model, thereby confirming that the independent variables contribute significantly to enlightenment on GDP variation.

The sum of squares of the regression, 0.202, represents the amount of variance in GDP accounted for by the independent variables. In contrast, the residual variance, 0.026, reflects the unaccounted variance, or the estimated error term. The large ratio of explained variance-regression sum of squares-to unexplained variance-residual sum of squares-points to the strength arising from the model, while accounting for changes in GDP related to port operational performance. These findings are supported by the fact that, in economic theories, there is an indication that effective infrastructure, it includes the condition of existence of good ports, which is conducive to the economic growth of developing countries with large reliance on maritime trade (Cullinane and Wang, 2010; Notteboom and Rodrigue, 2005).

**Table 19:** Coefficient Table

| Predictor | Unstandardized Coefficients (B) | Std. Error | Standardized Coefficients (Beta) | T | Sig. (*p-value*) |
|---|---|---|---|---|---|
| ***Constant*** | *22.935* | *1.524* | | *15.051* | *0.001* |
| Waiting Time (days) | -0.008 | 0.036 | -0.117 | -0.222 | 0.831 |
| Vehicle Traffic | 0.015 | 0.025 | 0.201 | 0.59 | 0.576 |
| Personnel | -0.015 | 0.055 | -0.133 | -0.273 | 0.795 |
| Gross Registered Tonnage | -0.009 | 0.03 | -0.156 | -0.295 | 0.776 |
| Ship Traffic | 0.074 | 0.047 | 0.544 | 1.591 | 0.172 |
| Berth Occupancy (%) | -0.067 | 0.044 | -0.573 | -1.528 | 0.187 |
| Turnaround Time | 0.023 | 0.064 | 0.112 | 0.365 | 0.729 |
| Cargo Throughput (tons) | 0.027 | 0.022 | 0.371 | 1.245 | 0.268 |

**Source:** Authors computation (2024)

The coefficient analysis in Table 19 explores the connection between Nigerian seaport operational performance variables and GDP. The constant term (B = 22.935, $p < 0.001$) represents the predicted GDP when all other variables are zero, serving as a baseline reference (Field, 2018).

Among the predictors, Ship Traffic shows the most positive influence on GDP (B = 0.074, $p = .172$), indicating that increased ship utilization is associated with higher economic output. However, this effect is not statistically significant at the 5% level (Tabachnick & Fidell, 2019). Similarly, Cargo Throughput exhibits a positive but statistically insignificant effect (B = 0.027, $p = .268$), consistent with previous findings highlighting its role in economic growth (Notteboom & Rodrigue, 2005).

On the other hand, Berth Occupancy (B = -0.067, $p = .187$) and Waiting Time (B = -0.008, $p = .831$) have negative coefficients. These results suggest that congestion at berths and delays negatively impact GDP, although these effects are not statistically significant. The standardized coefficients (Beta) further reveal that Berth Occupancy (Beta = -0.573) and Ship Traffic (Beta = 0.544) emerge as relatively stronger predictors of

GDP, despite their individual impacts being unsubstantial (Hair *et al.*, 2019).

Overall, the lack of significant individual predictors underscores the critical role of collective port performance in supporting economic growth. This aligns with research emphasizing the importance of trade efficiency for economic development in emerging markets (Notteboom & Rodrigue, 2005).

## CONCLUSION AND RECOMMENDATIONS

The assessment of Nigerian ports through DEA and SFA has unveiled critical inefficiencies alongside opportunities for growth. While Warri and Onne have consistently demonstrated high efficiency, Apapa and TinCan Island face challenges stemming from resource mismanagement and operational shortcomings.

Efficient personnel deployment is crucial. Warri's success with fewer staff highlights the importance of optimized workforce allocation, whereas Apapa's overstaffing failed to translate into proportionate gains. Introducing flexible, data-driven staffing strategies can better match workforce levels to operational demands.

Berth utilization plays a vital role in port efficiency. TinCan Island's peak berth occupancy of 71.3% illustrates the benefits of balanced capacity management. To improve, ports like Apapa and Warri should embrace predictive berth scheduling and expand infrastructure to maintain berth occupancy within the ideal range of 50-70%, minimizing delays and enhancing vessel turnaround.

Addressing vessel and vehicle traffic congestion is a pressing need. Onne and Warri require advanced traffic management systems and increased docking capacities. Similarly, Apapa and TinCan Island must prioritize improving road access and cargo transport systems to ease vehicle congestion.

Minimizing turnaround and waiting times is essential. This goal can be achieved by streamlining operations and adopting predictive resource allocation methods. Upgrading infrastructure to accommodate larger vessels and higher Gross Registered Tonnage (GRT) is equally important. By leveraging technology-driven solutions and adopting industry best practices, Nigerian ports have the potential to significantly boost efficiency, competitiveness, and their overall contribution to the national economy.

The GDP and seaport operations in Nigeria are related, which emphasises how important port efficiency is to economic expansion. Important metrics that have a positive effect on GDP include ship traffic and cargo throughput, which account for 88.7% of the variation in economic output. Even though waiting time and berth occupancy have detrimental effects, they are not statistically significant. This demonstrates that in order to strengthen Nigeria's maritime economy, port operations must be improved overall. In addition to expedited customs processes and strategic international partnerships, it is advised that investments in infrastructure, technology, and workforce development be given top priority in order to improve port efficiency.

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