

Optimizing Berth Allocation at Lekki Deep Sea Port: A Predictive Model for Efficiency and Growth

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Abstract

Seaports are essential for global trade, acting as vital hubs within vast freight transport networks. Efficient berth allocation is critical for smooth port operations, minimising vessel wait times, and optimising resource use written.

Purpose – This study analyzed berth utilization, vessel service times, traffic seasonality, and revenue at Lekki Deep Seaport.

Methodology – This study uses Python-based simulation and data visualisation to analyze berth allocation at Lekki Deep Sea Port, considering factors like vessel arrival rates (averaging one every 2.5 days), service times (1.5 to 2.5 days based on vessel size), berth utilisation under different traffic scenarios, revenue, idle costs, and congestion management via predictive modelling. Findings indicate that the current berth infrastructure is sufficient under present traffic conditions.

Findings – Findings indicate that the current berth infrastructure is sufficient under present traffic conditions. However, to prepare for future challenges, proactive measures like optimizing service times and implementing machine learning models are recommended as traffic grows to maintain efficiency. This study offers valuable insights for optimizing port operations and ensuring Lekki Deep Sea Port's continued contribution to West African economic growth.

Originality – Simulation techniques replicate port operations, helping identify bottlenecks and test allocation scenarios

INTRODUCTION

Seaports are essential for global trade, serving as gateways for goods that move between land and sea. These complex hubs encompass infrastructure, operations, and various stakeholders (Pietrzak & Pietrzak, 2021). A key operational component of any seaport is its berthing system, which manages the docking, handling, and departure of vessels. A berth is a designated location within a port where a vessel moors for loading and unloading cargo and passengers (Luo, Song, & Zhou, 2024). Efficient berth

allocation is essential to ensuring smooth port operations, reducing vessel waiting times, optimizing resource utilization, and ensures smooth goods flow (Stopford, 2009; Onwuegbuchunam, 2018).

Berths are specialized areas equipped with infrastructure, such as cranes, conveyor belts, and storage facilities, for handling various cargo types (Mhd Ruslan & Nazri, n.d.). Their size and capacity depend on the vessels they accommodate (Rajendran, Srinivas, & Saha, 2015). Modern ports employ advanced technologies, including automated systems and traffic management, to streamline berthing operations, thereby maximizing throughput and reducing turnaround times (Tan & He, 2021). Connecting seaports to national rail networks enhances competitiveness through seamless intermodal transportation (Pietrzak & Pietrzak, 2021). Strategic berth allocation and management are critical for port performance and contribution to trade networks (Rajendran et al., 2015).

The vessel's overall length has a significant impact on berth design and seaport operations. Longer vessels require longer berths for safe and efficient accommodation (Tan & He, 2021; Yang et al., 2024). This has implications for berth construction and ongoing port infrastructure management. Larger vessels, particularly mega-ships in container shipping, often require deeper drafts and wider beams (Budipriyanto et al., 2015). This necessitates dredging to ensure adequate channel depth and width for safe navigation and berth access. A vessel's dimensions, including length, affect maneuvering characteristics within a port. Longer vessels typically require larger turning basins and wider channels, increasing demands on port infrastructure and potential accident risks (Allen & Thiessen, 2007). The increased size also impacts the required terminal area and equipment for efficient loading/unloading (Allen & Thiessen, 2007).

Port authorities and terminal operators must consider vessel LOA when designing berths and planning infrastructure. Failing to account for increasing vessel sizes can limit a port's capacity to handle larger ships, impacting competitiveness and efficiency (Rodrigue, Slack, & Comtois, 2017). The trend toward larger vessels has driven investments in port infrastructure, including berth expansions, new terminal construction, and improvements in dredging and navigation systems (Pietrzak & Pietrzak, 2021; Stopford, 2009). Flexible berthing strategies can optimize shoreline usage and reduce the required berth length compared to fixed berthing methods (Djelović & Medenica Mitrović, 2017). Furthermore, factors like passing ships in river channels and environmental conditions (Headland & Poon, 1999) can also influence mooring operations and berth design.

Modern berth management utilizes advanced simulation models and algorithms to optimize scheduling and resource allocation. Simulation techniques replicate port operations, enabling the identification of bottlenecks and testing allocation scenarios. Machine learning algorithms forecast vessel traffic and predict waiting times, enabling proactive berth scheduling and improving overall port efficiency.

Review on Berth Allocation

Noritake and Kimura (1983) delve into the critical aspects of port infrastructure planning, focusing on determining the optimal number and capacity of berths in seaports. They offer an approach that integrates operational and economic factors to aid in effective port development. The paper established the framework for identifying the optimal number and capacity of berths in seaports, considering the dynamic nature of cargo demand and ship arrivals. The authors develop a queuing theory-based approach to model the port system, treating the arrival and service processes of ships as stochastic events. The queuing theory approach provides a foundational methodology that can be adapted and extended with contemporary data and computational tools to address current and future port planning needs. The findings suggest that there is an optimal point where the combined costs are minimized, providing a clear guideline for determining the appropriate number and capacity of berths. This balance ensures that ports can handle expected traffic efficiently without overinvesting in infrastructure that would remain underutilized.

Despite being conducted in the early 1980s, the principles outlined in this study remain highly relevant. Modern ports continue to face challenges related to fluctuating demand and the need for cost-effective infrastructure development. Meisel and Bierwirth (2013) present a comprehensive framework

for optimizing berth allocation and crane operations in container terminals. Traditional sequential planning approaches, which often treat berth allocation, crane assignment, and crane scheduling as separate processes, can lead to resource underutilization, increased operational costs, and inefficiencies in terminal operations. The authors propose an integrated approach that enhances decision-making by considering these interdependent processes collectively. The framework begins with the estimation of crane productivity rates based on detailed vessel stowage plans. This phase is critical in predicting the operational complexities of loading and unloading activities, ensuring that service time predictions are more accurate and reflective of real-world conditions. By accounting for the unique characteristics of each vessel's cargo configuration, this step lays a robust foundation for subsequent operational decisions.

Following this, the framework focuses on optimizing berth allocation and crane assignment. In this phase, berth assignment decisions are made in conjunction with crane availability and capacity considerations. This integrated approach ensures that berths are allocated not just based on space availability but also on the optimal deployment of cranes, thereby reducing the likelihood of scheduling conflicts and idle times. This synergy between berth and crane planning contributes to smoother operational flows and improved terminal throughput. The final phase involves detailed crane scheduling, which aligns with the earlier berth and crane assignment decisions. This phase seeks to minimize crane idle times and maximize their utilization by ensuring that crane movements and assignments are efficiently coordinated throughout the vessel-handling process. The result is a significant reduction in operational delays and an overall improvement in efficiency. Meisel and Bierwirth (2013) demonstrate notable improvements over traditional sequential planning methods. It ensures better resource utilization, reduces operational costs, and enhances the flexibility and adaptability of terminal operations. The approach is computationally efficient and applicable to a wide range of operational scenarios, making it a valuable contribution to the literature on integrated operations planning in container terminals.

Djelović and Mitrović (2017) categorize the factors affecting berth productivity into several groups. These include port infrastructure (berth depth, quay construction), superstructure (port machinery and storage facilities), organizational factors (workforce organization, management models), and environmental factors (climatic conditions, administrative procedures). Recognizing and optimizing these elements is essential for enhancing berth productivity. The research identifies significant differences between gross and net berth productivity. Non-operational times, such as equipment checks and administrative delays, significantly contribute to overall berth time. Minimizing these non-operational intervals can lead to improved efficiency and reduced ship turnaround times. Their work examines how berth productivity can fluctuate due to factors such as cargo type, handling methods, and vessel characteristics. Understanding these dynamics helps in developing strategies for efficient berth management. The research advocates for continued investigation into the correlation between identified influencing factors and berth productivity. This would facilitate the development of optimized management models aimed at reducing ship turnaround times and enhancing port efficiency.

Li and Jin (2009) tackle the optimization of berth allocation and quay crane assignment, significantly enhancing the efficiency of seaport container terminals. The authors aim to enhance resource utilization and operational efficiency by focusing on fluid berth configurations, which provide vessels with flexible docking options. This study presents a mathematical model that considers berth allocation and quay crane assignment simultaneously, reflecting the complex interdependencies between these operations. This approach differs significantly from traditional methods, addressing those problems in isolation, resulting in subpar outcomes. The authors' model incorporates numerous operational constraints, such as vessel arrival times, handling requirements, and quay crane availability, thereby providing a comprehensive optimization framework. Authors utilize specialized methods beneath murky circumstances surrounding proposed models with complex scales. Results show that their approach significantly enhances terminal performance through reduced vessel waiting times and improved berth utilization overall.

Aljuaid et al. (2024) focus on mathematical programming formulations for berth allocation problems in container seaport terminal facilities. The research analyzes port activities as processes that can be optimized through the development of two interrelated, sequential mathematical models. The

primary model is a Mixed Integer Linear Programming (MILP) model that captures the objective of minimizing the time vessels spend in traffic within the port. This model has both static and dynamic versions, reflecting the reality of berth allocation problems where both scheduled arrivals and available berths are considered. The secondary model with the least two goals in the programming focuses on transferring time to the storage area of containers to minimize the number of containers used for storage. This aids in decreasing the spread of containers, hence facilitating operational efficiency. All the frames were tested against contemporary and historical data from literature and ports, which proved their effectiveness and relevance. The research addressed the challenges of planning container storage and the simultaneous processing of vessel berthing at a single port.

RESEARCH METHOD

This case study analyzes berth allocation at Lekki Deep Sea Port using simulation and predictive analytics. This analysis aims to provide insight into optimizing port operations, ensuring that Lekki Deep Sea Port effectively catalyzes economic growth in West Africa, despite current challenges (Ogunlesi, 2023). The port's projected contribution of \$158 billion in direct and induced business revenue, its potential multiplier effect exceeding 230 times the construction cost, and its anticipated aggregate macroeconomic impact of \$361 billion over 45 years, highlight its importance to Nigeria's economy (Ogunlesi, 2023). This \$1.5 billion project, a joint venture between the Nigerian Ports Authority, Lagos State Government, Tolarams Group, and China Harbour Engineering Company (Ogunlesi, 2023), underscores the significance of efficient port operations for long-term economic benefits.

Data, including vessel names, estimated arrival and departure times, and actual berthing times, were sourced from lftng.com. Vessel details, such as LOA, were obtained from vesselfinder. The key operational characteristics examined through data visualisation are: Average vessel arrival rate, service times (correlated with vessel size), berth utilization under various traffic conditions, revenue per vessel type, Idle costs, and Congestion management through predictive modeling of vessel waiting times.

RESULTS AND DISCUSSIONS

1. Berth Allocation Analysis at Lekki Deep Sea Port

Figure 1: The Lekki Deep Sea Port, located in the Lagos Free Zone, Nigeria, is a critical infrastructure development for West Africa (Ogunlesi, 2023). As Nigeria's largest seaport and one of the region's most advanced, it is designed to accommodate large vessels and high-volume cargo traffic, serving as a regional transshipment hub (Ogunlesi, 2023). Key features include a 16.5-meter dredging depth, a 680-meter quay length, and a 1,909-meter breakwater. The port boasts two container berths, 680 meters long, capable of handling Post-Panamax vessels and other vessels with a Length Overall ranging from 120 to 400 meters. This capacity allows the port to accommodate 18,000 TEU container vessels, supporting its strategic role in regional trade. It operates 24/7, utilizing modern equipment for efficient cargo clearance and contributing to a more economical and comprehensive service offering within the Free Zone. While the port's annual throughput capacity is 1.2 million TEUs, current economic conditions have impacted its volume since operations began in April 2023 (Adepoju, 2024).



Figure 1: Lekki Deep Seaport Berth

Table 1: 2024 Lekki Deep Seaport Vessel's Berth Data

Vessel LOA (m)	Arrival (days)	Departure (days)	Time in Port (days)	Assumed Revenue (\$)
170	3.22	4.77	1.55	6,800
366	7.07	9.57	2.50	14,640
280	11.56	13.26	1.70	11,200
300	14.54	17.04	2.50	12,000
270	19.39	21.87	2.47	10,800
140	27.49	29.69	2.19	5,600
140	34.06	36.25	2.19	5,600
230	36.58	38.18	1.60	9,200
230	38.76	40.36	1.60	9,200
170	43.90	45.45	1.55	6,800
130	49.04	50.81	1.77	5,200
350	56.71	59.21	2.50	14,000
300	59.67	62.17	2.50	12,000
300	65.59	68.41	2.50	12,000
300	73.29	75.79	2.50	12,000
290	83.41	85.45	2.03	11,600
200	86.86	88.79	1.93	8,000
240	92.67	94.96	2.29	9,600
230	96.75	98.34	1.60	9,200
300	99.91	102.41	2.50	12,000
330	104.32	106.82	2.50	13,200
250	108.13	110.51	2.38	10,000
240	113.25	115.54	2.29	9,600
240	115.59	117.89	2.29	9,600
240	119.73	122.02	2.29	9,600
190	125.56	127.62	2.06	7,600
300	128.22	130.72	2.50	12,000
120	131.27	133.22	1.95	4,800
270	135.69	137.90	2.22	10,800
220	138.54	140.83	2.29	8,800
200	141.62	143.55	1.93	8,000
290	147.51	149.55	2.04	11,600
120	150.80	152.75	1.95	4,800
150	153.85	155.86	2.01	6,000
280	159.56	161.26	1.70	11,200
170	161.34	162.89	1.55	6,800
300	166.05	168.55	2.50	12,000
280	170.09	171.79	1.70	11,200
250	179.75	182.13	2.38	10,000
300	182.39	184.89	2.50	12,000
270	188.19	190.41	2.22	10,800
300	192.87	195.37	2.50	12,000
320	198.73	201.23	2.50	12,800
250	202.30	204.69	2.38	10,000
260	208.29	210.36	2.06	10,400
280	213.33	215.03	1.70	11,200
366	216.09	218.59	2.50	14,640
250	218.88	221.27	2.38	10,000
366	222.15	224.65	2.50	14,640
200	229.57	231.50	1.93	8,000
330	233.72	236.22	2.50	13,200
120	236.46	238.41	1.95	4,800
320	241.56	244.06	2.50	12,800
170	244.23	245.79	1.55	6,800
180	246.48	248.93	2.44	7,200
260	250.54	252.61	2.06	10,400
140	253.49	255.68	2.19	5,600
340	258.81	261.31	2.50	13,600
366	265.33	267.83	2.50	14,640
240	277.56	279.85	2.29	9,600
290	280.32	282.36	2.04	11,600
270	283.14	285.61	2.47	10,800
250	295.29	297.68	2.38	10,000
300	298.26	300.76	2.50	12,000
150	302.04	304.04	2.01	6,000
350	307.89	310.39	2.50	14,000
360	312.99	315.49	2.50	14,400
160	318.74	321.07	2.33	6,400
160	325.17	327.50	2.33	6,400
280	332.75	334.45	1.70	11,200
200	335.68	337.61	1.93	8,000
170	338.28	339.84	1.55	6,800
330	342.23	344.73	2.50	13,200
240	346.72	349.01	2.29	9,600
330	356.57	359.07	2.50	13,200
220	361.58	363.88	2.29	8,800

Source: Vesselfinder (2024) and <https://www.lft-ng.com/tools/vesselSchedule>



Figure 2: CMA CGM Scandola at Lekki Deep Seaport Berth

This section presents an analysis of berth utilization, vessel service time, seasonal variations in ship traffic, and their financial implications on port operations. The results are interpreted based on observed trends in vessel arrivals, berth occupancy, and cost distribution. The insights derived from these findings offer valuable implications for optimizing Lekki Deep Seaport berth efficiency and mitigating congestion risks.

Figure 3 reveals a significant imbalance in berth utilisation at the Lekki Deep Sea Port terminal from vessel calls in 2024. With only 20% of berth capacity actively utilized for vessel operations, 80% remains idle. This low utilization rate raises concerns about the port's operational efficiency and revenue generation potential. Several factors may contribute to this, including low vessel traffic, suboptimal scheduling practices that lead to inconsistent vessel arrivals, or other operational constraints. While the current berth infrastructure appears sufficient under present conditions, it is crucial to understand that proactive measures are not just beneficial but essential to maintain efficiency and avoid potential bottlenecks as traffic increases. Strategies to improve berth utilization involve optimizing vessel scheduling, attracting more vessel calls, and enhancing overall berth allocation efficiency.

Figure 4 pie chart is a simple financial analysis of the port. It clearly shows a pressing need for improvement: while revenue generation stands at a moderate 50%, it is severely undermined by high idle costs, which account for 20%. This inefficiency results in a net profit of only 30%. Addressing these operational gaps is not just advisable but essential for long-term success. To improve performance, focus should be on three critical areas: reducing idle costs, boosting revenue, and maximizing profitability. The current idle cost of 20% signifies significant under-utilization of resources, likely stemming from berth idleness, operational delays, or other inefficiencies. It is imperative to reduce idle costs below 10% through strategic enhancements in berth scheduling, improved yard planning and equipment utilization, and dynamic pricing for berth allocation. Increasing revenue is equally vital.

Lekki Deep Seaport can attract more vessels by implementing competitive tariffs and offering enticing incentives. Expanding value-added services, such as container storage and repair, optimizing cargo handling rates based on real-time demand, and strategically scaling terminal capacity will drive significant growth. Maximizing profit requires the port to prioritize substantial cost reductions alongside revenue enhancements. Improving turnaround times leads not only to faster vessel processing, but also to higher throughput, increased revenue, and lower operational costs. Rigorous monitoring of key performance indicators (KPIs), like berth utilization, dwell time, and turnaround efficiency, is essential to achieve these goals.

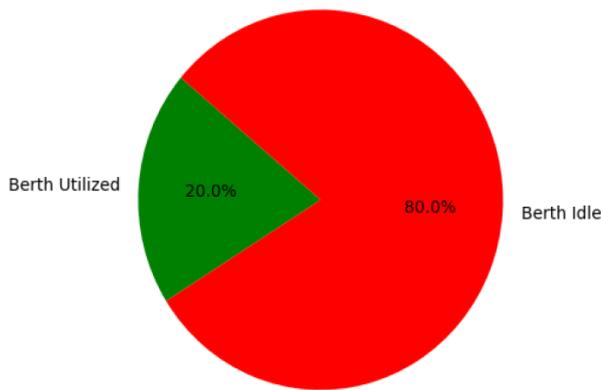


Figure 3: Lekki Deep Seaport Berth Utilisation

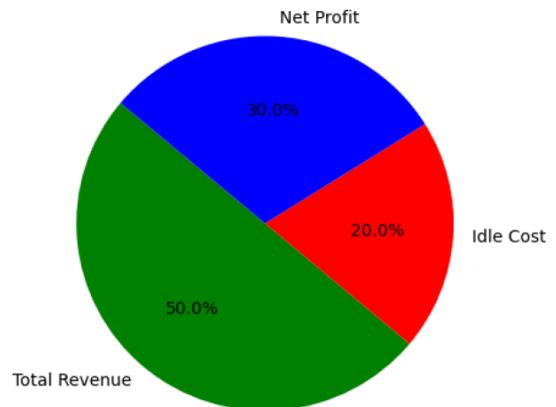


Figure 4: Revenue, Idle Cost, and Net Profit

Figure 5 shows the revenue distribution in the port during peak and nonpeak periods showing a nearly balanced split, with off-peak revenue slightly higher at 51.5% compared to 48.5% during peak times. This indicates a relatively stable demand throughout the operational periods. While current off-peak utilization appears effective, strategies such as discounted rates, storage incentives, or flexible berthing options could further boost off-peak earnings. On the other hand, if peak periods are expected to generate significantly higher revenue, it could be beneficial to focus on increasing peak-time pricing, offering premium services during these busy periods, or improving operational efficiency to maximize revenue during times of high demand.

Figure 6 is the vessel Length Overall (LOA) in relation to service time at the port indicates a positive correlation: larger vessels typically require longer service times. The regression line in the scatter plot supports this trend, and the shaded confidence interval highlights the variability in service time predictions. Smaller vessels (those under 200m LOA) exhibit significant variability, with service times ranging from 1.6 to 2.4 days. This variability suggests potential inefficiencies or fluctuating operational factors such as berth availability and crane allocation. Mid-range vessels (200m to 300m LOA) generally follow the regression trend, although some outliers are present. Larger ships (over 300m LOA) consistently experience longer service times, clustering around 2.4 days or more, indicating a possible bottleneck. These findings imply that larger vessels necessitate more berth time due to increased handling complexity, higher container volumes, or equipment limitations. It is essential to consider both regular and emergent vessel arrivals when optimizing berth strategies, particularly for larger vessels, to ensure effective planning.

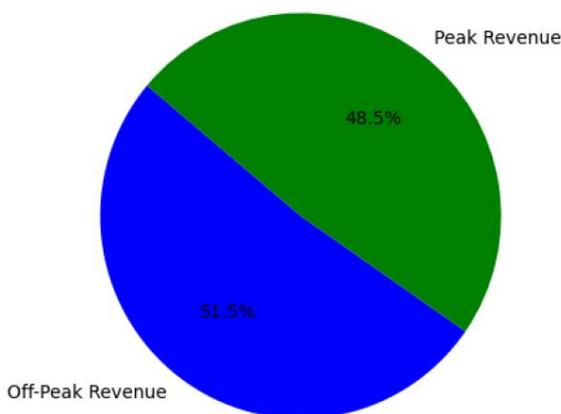


Figure 5: Peak vs. Off-Peak Revenue Distribution
 Source: Authors (2025)

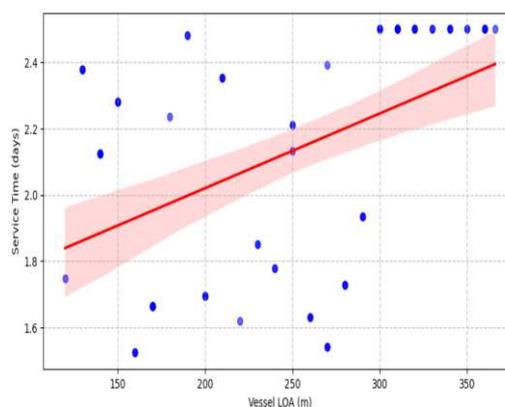


Figure 6: Vessel LOA vs. Service Time Chart

Figure 7 shows the heatmap, revealing monthly fluctuations in ship arrivals, which range from 5 to 9 per month. The month of July experienced the highest traffic, with nine arrivals, while August and December saw the lowest, with five arrivals each. Peak periods occur in May, June, July, and November, likely driven by increased trade demands. In contrast, August and December represent off-peak periods, possibly due to seasonal factors such as holidays or weather conditions. Operationally, higher ship arrivals suggest increased berth occupancy, revenue potential, and the risk of congestion. Conversely, lower arrivals during off-peak months lead to more idle berths and increased opportunity costs. Therefore, optimizing berth scheduling during peak months is crucial to mitigate congestion, while implementing cost-saving measures during off-peak periods can minimize idle costs. There is a need to analyze external factors, such as weather and trade cycles, to improve traffic forecasting accuracy, enabling the port to make informed decisions and be prepared.

Figure 8 depicts the violin plot of berth occupancy against vessel size distribution reveals a clear correlation between vessel LOA and time spent in port. Larger vessels (300m–360m LOA) consistently exhibit higher berth occupancy times, indicating longer service durations. Conversely, smaller vessels (120m–180m LOA) demonstrate shorter and more stable service times, likely attributed to simpler cargo operations and faster turnaround. A notable observation is the high variability in service times for vessels around 250m–270m LOA, suggesting inconsistencies in operational processes. This variability may stem from handling efficiency, cargo type, and berth availability. These findings highlight opportunities for enhancing port efficiency. Predictable service times for larger vessels facilitate optimized berth scheduling. In contrast, the unpredictable nature of mid-sized vessel service times suggests potential inefficiencies related to crane allocation, yard congestion, or weather-related delays. Optimizing port operations for vessels in the 250m–270m LOA range could significantly enhance overall berth utilization, offering a hopeful prospect for the future of port operations, and mitigate congestion.

Figure 7 presents the utilization of the Lekki Deep Seaport berth over time. It reveals a steady growth trend across 365 days, suggesting a rise in vessel traffic, improved port operations, or increased demand for terminal services. This trend’s smooth and progressive nature indicates a well-balanced berth scheduling system, minimizing congestion and sudden idle periods. The absence of sharp fluctuations further suggests consistent vessel traffic, with minimal extreme seasonal variations. Despite the positive growth in berth utilization, the fact that it remains below 25% presents us with a clear opportunity for improvement. This low utilization could be attributed to several factors, including inefficient berth allocation, excess berth capacity, or operational bottlenecks. Addressing these issues can significantly enhance the port’s efficiency and performance.

To address the issue of low berth utilization, several recommendations can be implemented. These include increasing vessel calls and throughput through improved scheduling and optimized berth allocation, as well as enhancing operational efficiency to reduce service time per vessel. However, if low berth utilization persists despite these efforts, it is crucial to conduct a cost-benefit analysis. This will help explore alternative uses for underutilized berth areas, potentially repurposing them for other port-related activities.

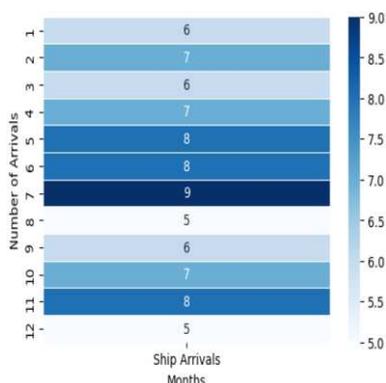


Figure 7: Seasonal Variations in Ship Traffic

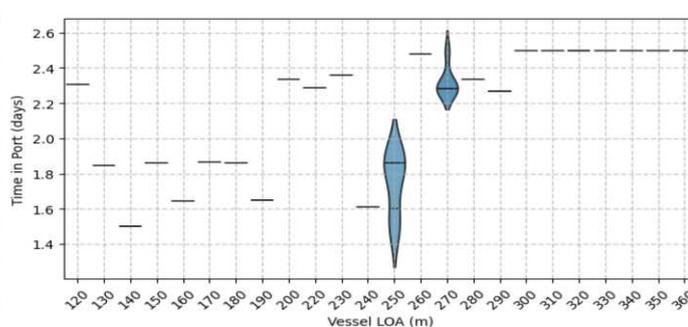


Figure 8: Berth Occupancy vs. Vessel Size Distribution

Figure 8 illustrates a Gantt chart analysis of berth occupancy, revealing valuable insights into port operations and potential areas for optimization. The horizontal distribution of vessel LOA indicates consistent ship arrivals throughout the year, a promising sign of steady demand for berth space. The chart also reveals varying vessel sizes, with larger ships (300m+) appearing periodically, likely due to their greater berth space requirements and the need for advanced scheduling. The gaps in the chart are not just empty spaces, but they signal periods of potential berth idleness or low demand, especially around certain intervals. Investigating the causes of these gaps, such as seasonal demand fluctuations, operational constraints, or scheduling inefficiencies, is not just a task but a critical mission for optimizing berth utilization.

The chart demonstrates the impact of increasing ship traffic on berth utilization under different arrival rate scenarios. Berth utilization increases with higher ship arrival rates, rising from approximately 25% at 2.5 days per ship to around 30% at 1.5 days per ship. While higher ship traffic can lead to increased berth occupancy and higher revenue, it is crucial to balance these gains with the risk of congestion. It is momentous to point out that low and excessively high berth occupancy ratios can incapacitate the port efficiency and profitability. This balance is not just a consideration, but a responsibility for all stakeholders in Lekki Deep Seaport's port operations.

CONCLUSIONS

This study analyzed berth utilization, vessel service times, traffic seasonality, and revenue at Lekki Deep Seaport. The findings reveal that increasing berth utilization led to congestion. Larger vessels require longer service times, highlighting the need for efficient scheduling. Seasonal traffic fluctuations necessitate adaptable resource management. Revenue is tied to berth occupancy, but cost control is crucial for profitability. Increased traffic requires strategic planning to minimize berth idle time and improve throughput. While the port operates at a high activity level, strategic interventions are needed to maintain efficiency, increase vessels call, and optimize revenue. We offer recommendations that are not just a roadmap for improvement in the Lekki Deep Seaport. Implementing them can improve berth efficiency, reduce costs, enhance service, and ultimately increase profitability and sustainable growth. They include that: authorities ensure optimize berth scheduling and allocation (dynamic models, prioritization based on vessel size and cargo); implementation of demand-based pricing (peak/off-peak pricing, incentives); improve data-driven decision-making (real-time analytics, digital berth management); manage seasonal variations (adjust staffing and resources, coordinate with shipping lines); and enhance stakeholder communication and collaboration (strengthen coordination, seamless information sharing).

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