Waiting Line Study of Ship-Truck-Cargo Transfer Operation in the Nigerian Seaports

DONATUS E. ONWUEGBUCHUNAM[1], HARRISON OBIORA AMUJI[2], KENNETH U. NNADI[1], KENNETH C. GODWIN[1], CHRISTY C. NWACHI[3], OJUTALAYO J. FOLAYAN[4], LOUISA N. AMAECHI[5], BRIDGET NWANYIBUIFE OKECHUKWU[6], VIVIAN NGOZI IKEOGU[7]

[1]Department of Maritime Science and Technology Federal University of Technology Owerri, Imo State NIGERIA
[2]Department of Statistics Federal University of Technology Owerri Imo State NIGERIA
[3]Department of Urban and Regional Planning Federal University of Technology Owerri, Imo State NIGERIA
[4]Department of Nautical Science Federal College of Fisheries and Marine Technology Victoria Island, Lagos NIGERIA
[5]Directorate of General Studies Federal University of Technology Owerri, Imo State NIGERIA
[6]Department of Statistics Federal University of Technology Owerri, Imo State NIGERIA
[7]Department of Logistics and Transport Technology Federal University of Technology Owerri, Imo State NIGERIA

Abstract: - Efficient cargo transfer operations are essential for optimal port performance. This study evaluates the operational effectiveness of ship and truck cargo handling systems at the Onne Port Complex using queuing theory. This paper assessed the system performance of ship and truck cargo operations at berths using queuing models and identified inefficiencies in vessel and truck processing times. The study adopted a survey design and collected primary and secondary data from 2014 to 2023. Queuing models were applied to analyse vessel and truck operations using parameters such as arrival rates, service rates, waiting times, and system utilization. The findings show that the ship's cargo transfer system utilization rate was 60%, with average time in system at 18 minutes and no queuing time, indicating idle berth capacity and delays due to facility readiness or documentation issues. However, in the case of the truck operation, we found very low utilization (18.4%), with trucks waiting an average of 13 minutes in the queue and 23 minutes in total within the system. This indicates poor efficiency despite an appointment system in place. The study concludes that both vessel and truck cargo handling systems at Onne Port are underutilized. Delays are mostly caused by operational and technological inefficiencies rather than congestion. Improvements in documentation processes and ICT integration are needed to enhance system performance. We therefore recommend the upgrade of ICT infrastructure, optimization of berth and truck scheduling systems, and enforcement of performance benchmarks to improve terminal operations in Nigerian ports.

Key-Words: - Waiting line, Ship Operation Cargo Operation, Berth Utilization, Service Rate, Arrival time Rate.

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1 Introduction

Increased global competition has resulted in increasingly congested shipping ports, waiting lines, and reduced productivity. To provide adequate space for the increased traffic, ports must either expand facilities or improve the efficiency of the operations to minimize losses [1]. This paper is devoted to the waiting line study on ship-truck-cargo transfer in the seaport for operational efficiency.

Ship-to-truck (STT) cargo transfer operation is a crucial process in seaports that involves the direct transfer of goods from vessels to trucks within port facilities. This operation plays a significant role in expediting cargo delivery, reducing costs, and enhancing supply chain efficiency. STT operations aim to minimize cargo dwell times, alleviate congestion in port areas, and optimize the utilization of both maritime and land-based transportation modes. The ship-to-truck cargo transfer operation in Nigeria's seaports faces several challenges. Some of the key issues include Exorbitant Cargo Transfer Charges, Congestion and Space Constraints, Regulatory Disputes, Inefficient Documentation and Procedures, and Potential for Discrepancies. These constraints have been linked to a lack of space at the terminals, which often leads to off-dock transfers of cargo and hence additional costs. Besides, complex documentation involving cargo manifests, discharge tally sheets, and transfer tally records manifests in inefficient documentation processes and impede the transfer process, thus raising costs. There are also issues of cargo damage and or losses emanating from ship to truck transfers, which add to the cost borne by cargo owners. The Nigeria Shippers Council (NSC), which is the technical regulator, has been involved in disputes with terminal operators over the legality and reasonableness of cargo transfer charges, highlighting the need for clearer regulations and guidelines. Some policies have been put forward by the NSC, which are as follows: Providing guidelines on setting and modifying tariffs, rates, and charges for service providers in the Nigerian port sector; establishing a complaints portal to address grievances and concerns from stakeholders; and developing standard operating procedures for cargo handling and transfer operations. Yet ship to ship-to-truck cargo handling operations at the ports leave much to be desired, thus necessitating the need for data-driven analytical solutions.

Research Problem & Context

The efficiency of ship-to-truck cargo transfer operations plays a critical role in the overall performance of seaport logistics and the global supply chain. Despite advancements in port infrastructure and technology, many Nigerian seaports continue to face operational bottlenecks, congestion, and delays during cargo transfer between maritime vessels and land-based transportation. These inefficiencies result in increased truck turnaround times, port congestion, higher logistics costs, and elevated carbon emissions due to idling and prolonged operations. One of the core challenges lies in the synchronization and coordination between port terminal operations, yard equipment scheduling, gate processes, and truck arrivals. Additionally, the lack of real-time information sharing, limited use of digitalization and automation technologies, and inadequate implementation of appointment systems contribute to poor operational performance. As global trade volumes increase and ports face mounting pressure to improve throughput while reducing environmental impact, it becomes essential to analyse, model, and optimize ship-to-truck cargo transfer processes. There is a growing need for data-driven decision-making frameworks and intelligent systems that can enhance coordination among stakeholders, reduce delays, and improve overall operational efficiency. Therefore, this research seeks to address the pressing problem of inefficient ship-to-truck cargo transfer operations; the research approach involves applying queuing theory (waiting line models) to analyse and improve cargo handling performance and truck service times at the port.

Research Objectives

i) To apply queuing models to assess the Ship and the Truck waiting times, service rates, and system utilization at seaports.

ii). To evaluate the effectiveness of ship and truck appointment systems and scheduling strategies.

2 Literature Review

Seaports serve as critical hubs in global trade, linking maritime and land-based transportation. The transfer of cargo from ships to trucks is a key activity in port operations, influencing turnaround times, supply chain efficiency, and cost effectiveness. Rodrigue and Notteboom [2] emphasized that intermodal efficiency in ports is crucial for just-in-time logistics, where delays in truck dispatch can lead to significant downstream disruptions. UNCTAD [3] highlighted that improving hinterland connectivity (especially road transport) is one of the top priorities for modern port infrastructure investments.

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congestion in port areas, and optimize the utilization of both maritime and land-based transportation modes. Automation, container cranes, automated guided vehicles (AGVs), and real-time tracking systems are some of the technological advancements that have transformed the STT process. STT operations are increasingly being integrated with other modes of transportation, such as rail and intermodal logistics networks, to create seamless cargo transportation solutions. The Ship-to-Truck Cargo Transfer Process involves multiple sub-operations: discharging containers from vessels using quay cranes, temporary storage in the yard, and retrieval and loading onto waiting trucks. Vis and de Koster [4] outlined the typical sequence of container handling operations and pointed out that truck-based pickups are often unscheduled and subject to high variability. Guo et al. [5] found that mismatches between crane discharge schedules and truck availability can result in yard congestion and excessive waiting times. Common bottlenecks in Ship-to-Truck Operations include a lack of synchronization between ship and truck schedules, gate congestion due to peak-hour truck arrivals, and limited stacking space. Zhang et al. [6] found that unscheduled truck arrivals lead to long queues at gates and create backlogs in yard operations. Giuliano and O'Brien [7] noted that 30–40% of truck delays occur at the gate due to verification and inspection processes.

The queuing system is a decision-making tool designed to help management make informed decisions [1]. To determine the optimum number of trucks at a seaport for transportation, the queuing theory is applied in light of port facilities and activities. Queuing models (e.g., M/M/1, M/M/c) have been used to study waiting lines at gates, crane operations, and yard truck dispatch points. Kim and Kim [8] used M/M/1 models to analyze terminal gate delays and proposed adding parallel service points (M/M/c) to reduce queues. Henesey [9] applied queuing models to simulate truck waiting times. Yoon [10] applied various queuing models to handle truck delays at the U.S container terminals. By analysing the additional truck turnaround time incurred at the inspection stations under various levels of security, the researcher estimated truck delay as containers are inspected at two successive security inspection stages.

El-Naggar [11] applied queuing theory to determine the optimal number of berths that minimizes the total port costs and meets future demand at the Alexandria port. Similarly, Gidado, U [12] applied a queuing model to determine the cause of congestion in African ports and found that poor planning, poor regulation, inefficiency, or a combination of these. These constraints, according to the researchers, translate into extra costs, loss of trade, disruption of trade and transport agreements.

Bandeira et al. [13] explored multi-server queues (M/G/c) to model the randomness of service times at container terminals. While queuing theory provides analytical insights, discrete-event simulation (DES) captures the complexity and stochastic nature of port systems. Chang et al. [14] developed a DES model to simulate ship-to-truck transfer operations. Heilig and Voß [15] emphasized the integration of simulation and optimization for container terminal performance assessment. The growing applications of technology and digitalization are such that Smart ports are increasingly using digital tools such as Truck Appointment Systems (TAS), GPS-based truck tracking, and yard management systems. Port of Rotterdam [16] adopted a digital twin approach. Zhou and Peng [17] showed that TAS can reduce average truck wait time by up to 35% when integrated with yard scheduling. Despite the advancements, several gaps persist, including limited real-world data integration, a lack of region-specific studies, minimal use of AI/ML, and inadequate modelling of dynamic arrival patterns.

3 Materials and Methods

The researchers adopted a survey research design to collect data on ship and trucking operations involving cargo transfer at the Onne ports complex. The secondary data was obtained from the traffic Department and covered ship and truck cargo transfer operations at the berths/quayside from 2014 to 2023. Table 1 contains data on the number of vessels that called for service at the berths, the arrival rate (per hour), and days spent while being worked on at the berths. Others include: crane efficiency proxy for service rate (of cargo handling operation), and number of berths (server) available at the port.

Table 1: Data on Ship Operations at Berth in Onne Port

S/N	Year	SCPR	AAR/h	DSAB	NBA	AST/hr
1	2014	413	0.534	5.56	9	2.22
2	2015	517	0.633	5.02	9	2.2
3	2016	861	2.359	2.98	6	2.39
4	2017	820	2.247	3.4	6	2.51
5	2018	433	0.562	5.1	8	9.52
6	2019	417	2.569	6.6	7	2.79
7	2020	450	2.672	6.4	5	2.61
8	2021	418	0.654	7.2	6	2.9
9	2022	452	2.569	5.7	7	3.08
10	2023	480	3.468	4.9	8	10.4

Source Author, fieldwork

Where Ship calls (nos.) per year = SCPR

Average Arrival Rate/hr = AAR/h

Days Spent At Berth = DSAB

No. of berths available = NBA

Similarly, in Table 2, we present data on the number of ships and trucks that were loaded with cargo or discharged of cargo at the port during the period under consideration. Others include the arrival rate of ships and trucks at the quay during loading or discharging operations, the crane efficiency (Ship's derrick), and the number of available berths where the cargo transfer operation was undertaken.

Table 2: Number of Trucks Handled at Onne Port

S/N	Year	TTA	TAP T/hr	AST /hr	NOB
1	2014	528	11	3.3	9
2	2015	192	10	3	9
3	2016	540	9	2.7	6
4	2017	324	9	2.6	6
5	2018	504	11	3.3	8
6	2019	420	8	2.4	7
7	2020	312	9	2.7	5
8	2021	252	7	2.1	6
9	2022	516	11	3.3	7
10	2023	300	8	2.4	8

Source: Authors, field work

where Truck Throughput (Annual) =TTA
Trucks Arriving Port for Transfer/hr = TAPT/hr
Ave. service time per hr =AST/hr
No. of berths (c) = NOB

3.1 Measure of Performance

In this paper, the queuing analysis was carried out with various operating characteristics to measure performance. This analysis was based on;

L_q = number of vessels or trucks in the queue

p_n = probability of n vessels or trucks in the system

c = number of service channels

L_s = total number of vessels or trucks available for the transfer of cargo

λ = arrival rate of vessels or trucks

μ = service rate of vessels or trucks

W_s = the average waiting time in the system

W_q = average waiting time in the queue.

P_w = probability that arriving vessels or trucks to wait = $1-P_0$

The core objective of this work is to assess port systems' performance in terms of cargo operations involving ships and cargo trucks. Two scenarios are examined here; in the first scenario, we apply the model to assess the system performance of vessels in the queuing system in the port. In the second scenario, we determine how the characteristics of trucking at investing ports and entering the queuing system. The ship and trucks are port customers, and understanding their waiting line characteristics would provide a comprehensive framework for efficient management of port terminal operations and facilities.

In Table 3, we present the result of the waiting line analysis of the ship handling operation at Onne Port. The parameters (mean values) of the model determined include the following: the probability that the system utilization rate or capacity (P_0) = 60%**,** total number of vessels in the system (waiting and the ones being served) (L_s) = 1, Average number of vessels on queue (L_q) = 0. Others are: average time spent by vessel on queue (W_q) = 0 hours and average time spent by vessel in the system (W_s) = 0.3 hours. From the findings, we can infer that the port terminals (system of berths) are not efficiently utilized, some unutilized capacity (40%) still exists, hence no vessel is in queue (L_q) = 0, meaning a vessel is served immediately it is positioned for work at the berths. However, since L_s = 1; vessels still wait for 1 hour before being positioned for service at the berth; this explains why a vessel will wait for an average of 0.3 hour or 18 minutes in the system. This delay could be attributed to cargo handling facilities not being ready or documentation lapses. See Tables 3 and 4 in Appendices 1 and 2.

Similarly, in Table 4, we present the result of the waiting line analysis of the truck handling operation at Onne Port. The parameters (mean values) of the model determined include the following: the probability that the system utilization rate or capacity (P_0) = 18.4%**,** total number of trucks in the system (waiting and the ones being served) (L_s) = 4, Average number of trucks on queue (L_q) = 0. Others are: average time spent by truck on queue (W_q) = 0.22 hours and average time spent by truck in the system (W_s) = 0.39 hours. In evaluating the results, we find that the capacity utilization of the trucking operation at the port is very low, below average, that is to say that we have unused capacity of 82% (100-18%). In terms of other parameters, the average number of trucks in the queuing system is 4. Again, this value represents a truck waiting to be served (discharged or loaded) since the average number in the queue is zero. The results also indicate that trucks wait for an average of 13 minutes (0.22 hours) in the queue and a total of 23 minutes (0.39 hours) in the system (waiting for service + being served). This is not encouraging given that the system capacity is below optimum.

In summary, we note here that when we examine the queuing system performance of ship-berthship-berth operation, vessels are still delayed before being worked on, probably as a result of a lack of facility readiness or documentation lapses. Vessels are worked upon when eventually positioned, as the average time spent in the queue is zero. However, the berths and facilities are not optimally utilized as capacity usage is still below 100%. If we consider the trucking operation, we note that the truck appointment system in use has not raised efficiency levels at the terminals. The findings still show that trucks wait for an average period of 13 minutes before cargo operations can be initiated. The system performance is 18%. The concessioning of terminals with the expectation of facility upgrades from private operators no doubt has yielded some benefits. However, more attention should be given to terminal operation processes. Delays observed before the commencement of cargo operations could be eliminated if Information and Communication Technology (ICT) facilities are optimally deployed. System readiness is critical to efficient terminal operations, and terminal managers should ensure the facilities are ready for smooth cargo handling operations.

Summary:

The study investigates ship-to-truck cargo transfer operations at the Onne Port Complex using a queuing model approach. Secondary data from 2014 to 2023 were collected to assess system performance across two key operations: vessel handling at berths and truck cargo loading/discharge at the quays. The analysis applied queuing theory to estimate utilization rates, queue lengths, and wait times. Key findings include:

i) Ship Operation: Port terminal berths have a system utilization rate of 60%, with an average system time of 18 minutes. Although vessels don’t queue (Lq = 0), there’s still idle capacity (40%). The wait before service initiation could be attributed to documentation delays and the degree of readiness of cargo handling equipment.

ii) Truck Operation: System utilization was only 18.4%. Trucks still experience an average of 13 minutes in queue and 23 minutes total in the system. This low utilization reflects inefficient use of resources, even under a truck appointment system adopted by the Nigerian Ports Authority.

iii) Despite terminal concession and private investments, observed inefficiencies show a persistent delay in cargo handling processes.

Recommendations:

We recommend **an** upgrade in ICT Systems: This could be achieved by automating cargo documentation and clearance processes to reduce delays in initiating operations. There should be optimization of facility use. In this case, berth allocation and truck appointment systems should be reassessed to maximize the usage of existing infrastructure. Training and Capacity Building are also needed. Terminal staff should be trained on logistics coordination, ICT usage, and real-time operations monitoring. Port administrators/regulators should also set performance benchmarks for private terminal operators to ensure consistent service levels. Terminal operators should develop real-time traffic and logistics management systems for trucks and port entry scheduling.

Areas for Further Study:

Future research should focus on the following areas: evaluation of how ICT interventions impact cargo dwell time and turnaround; comparative analysis of differences between Nigerian and international ports in cargo transfer metrics. Others include: cost-benefit analysis of idle capacity, especially on quantifying the economic loss associated with underutilized berth and truck handling capacities, and a survey of port users to identify hidden operational challenges not captured in system performance data.

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Appendix

Table 3: Queuing Model Characteristics of Ship Handling Operations in Onne Port's Complex

Scenarios	**c**	λ	μ	λ_{eff}	P_0	L_s	L_q	W_s	W_q
1	9	0.53	2.22	0.53	0.788	0.239	0	0.45	0
2	9	0.63	2.2	0.63	0.751	0.286	0	0.455	0
3	6	2.36	2.39	2.36	0.373	0.988	0	0.418	0
4	6	2.25	2.51	2.25	0.408	0.896	0	0.398	0
5	8	0.56	9.52	0.56	0.943	0.059	0	0.105	0
6	7	2.57	2.79	2.57	0.398	0.921	0	0.358	0
7	5	2.67	2.61	2.67	0.359	1.024	0.001	0.384	0
8	6	0.65	2.9	0.65	0.799	0.224	0	0.345	0
9	7	2.57	3.07	2.57	0.433	0.837	0	0.326	0
10	8	3.47	10.44	3.47	0.717	0.332	0	0.096	0
Average	-	-	-	1.83	0.6	0.581	0	0.334	0

Table 4: Queuing Model Characteristics of Trucking Operations At Onne Ports Complex

Scenarios	**c**	λ	μ	λ_{eff}	P_0	L_s	L_q	W_s	W_q
1	9	11	3.3	11	0.036	3.338	0.005	0.303	0
2	9	10	3	10	0.036	3.338	0.005	0.334	0
3	6	9	2.7	9	0.346	3.519	0.185	0.391	0.206
4	6	9	2.6	9	0.302	3.694	0.232	0.41	0.258
5	6	11	3.3	11	0.035	3.519	0.185	0.32	0.017
6	7	8	2.4	8	0.354	3.389	0.056	0.424	0.696
7	5	9	2.7	9	0.318	3.987	0.653	0.443	0.726
8	6	7	2.1	7	0.346	3.519	0.185	0.503	0.265
9	7	11	3.3	11	0.035	3.389	0.056	0.308	0.005
10	8	8	2.4	8	0.036	3.35	0.016	0.419	0.002
Mean	-	-	-	9.3	0.184	3.504	0.158	0.385	0.218

Source: Authors, data analysis