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Research Article

Estimating truck queue length at Nigeria seaport: State-Dependent Approximation Model

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Abstract— The aim of the study is to estimate the truck queue length calling at Nigeria seaport with a focus to determine the queue formation state and queue dispersion using State-Dependent Approximation Model. To do this, trucks traffic for calling truck at the Apapa complex ports was examined for a period of seven days starting from 12:01 midnight to 12:00 on each day. At the end of the assessment period, five thousand one hundred and two (5102) trucks were recorded and used for analysis. The data of the study was sorted and analyzed using Microsoft Excel analytical software. The regression result analysis for queue formation state show that it took less an hour for queue to reach its steady-state i.e. critical point for queue formation process shows a value of 0.6. The result on queue dispersion state show that it took a truck several hours to truck to dispersed or leave the gate with critical point of queue dispersion state shows a value of 40.16. the study recommended that Nigeria port authority need to implement gate appointment system (GAS) method of the management of truck arrival into the port in order to reduce the waiting time of truck (dispersion state) in Nigeria seaport.

Keywords— State-Dependent Approximation Model, Arrive time, formation state, dispersion state, Apapa port.

1. Introduction

As the port and its activities continue to expand, many ports across the global including their immediate surrounding communities are experiencing huge traffic congestion at the container marine terminal gate (CMTG) [1]. Container marine terminals (CMT) refer to the area or places where most of the world's international goods are transferred to other modes of transport. As a result of these, container marine terminal become most attractive for trucks to come for loading and offloading of cargoes. According to [2], estimated that about 85% of global trade and over 75% of its value are moved onboard ships and managed by seaports worldwide through container terminals. The report presented in Figure 1 highlight the level of maritime trade increased at a compound annual rate of 4 percent since the past decade. In 2023, the total maritime trade will have grown almost three times since 2005.

However, the compound annual increase in international maritime trade shown in Figure 1 has a negative impact along the roadway transportation systems of the metropolitan areas, especially around seaports and industrial areas, causing truck congestion and delays at the terminal gates. The congestion which automatically increase the truck waiting time, is not only economic affecting the well-being of the truckers, but it also seriously hampers the day-to-day operation of ports and other nearby businesses along the hosting communities, causes supply chain disruption, and contributes significantly to air pollution. The environmental effects resulting from idling trucks according to [3], is a serious issue within the communities, as truck emissions have been linked to some sickness such as heart disease, cancer, and asthma.

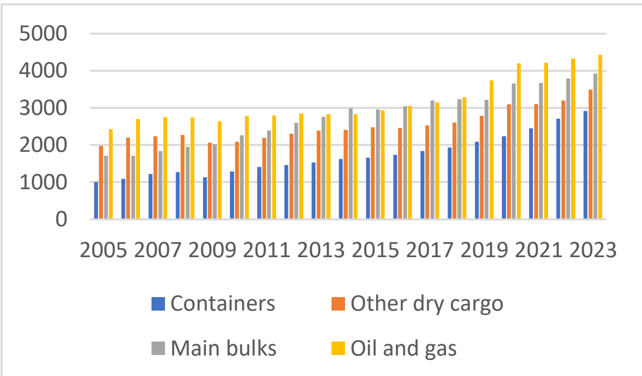

Figure 1. International maritime trade flow as from 2005 to 2023.
Source: UNCTAD (2023)

As many ships arrive at the terminals for offloading and loading containers, it can be expected that more pressure or growing activities will be on the marine terminal gates due to the fact that marine terminals are mostly located in or near major cities, where right of way is limited and very expensive [4]. Therefore, considering the aforementioned arguments, the aim of this study is to estimate the truck queue length, formation period, dispersion state at the Nigerian seaport using a state-dependent approximation method. The method is adopted because it considers both the queue formation and dispersion processes.

2. Related Work

Several studies on traffic congestion at the marine container terminal and terminal gate has been study using several approaches and strategies to determine the waiting time, service time, and turnaround time of trucks in order to improve operational efficiency, and minimize environmental issues affecting the hosting community. On the other hand, several studies used models such as queuing models, fluid flow models, simulation-based models, and regression models to predict the length of queue at the various seaport, bus station, terminal gates, and canter. For example, [5] investigate the waiting arrival time, service time, and turnaround time of ships calling at the Apapa Port Complex and Tincan Island Port using queue simulation techniques. [7] estimated the truck delay at the container port using M/M/1 and M/M/S queuing models. Also, [8] uses the application of multi-server M/Ek/s queuing model to analyze truck congestion at the terminal gate and to quantify the cost associated with the waiting time of trucks. This study was expanded by [9]. [10] developed state-dependent approximation method and used the mode to estimate the truck queue length, formation state and dispersion state of truck at marine terminals gate. [11] on their recent study on terminal gate look at the impact of service policies efficiency using a simulation approach. The simulation results indicate that a gate-sharing policy can reduce truck congestion at a certain arrival rate. On the other hand, [12], [13], [14], and [15] studied the application truck appointment system method to avert truck congestion at many developed ports. Most of the study found that the use of truck appointment system enhanced smooth port operations by reducing truck queueing time and resulting in less congestion. Few studies concluded that the truck appointment system does not improve waiting times. [16] developed optimisation models to determine the optimal number of gate lanes. [17] adopted a fluid flow model to study telecommunication and vehicle queues at roadway intersections in order to minimise the total waiting time. Discrete event simulation model FlexSim was used by [18] to study the long truck turn times for external trucks at marine container terminals. [19] used ARENA, a discrete event simulation software, to measure the performance of a container terminal system by focusing attention on ship waiting times, queue time, the number of containers in the queue, the resource usage rate, and the number of loading and unloading containers.

From the above literature review, it shows that the previous studies on the existing models (queuing models, fluid flow models, simulation-based models, and simulation-based regression models) used to estimate ship and truck queue length at the marine terminals and gates have their limitations and cannot give accurate ship and truck queue length estimation under certain conditions. Therefore, this study is to close the gap or limitation of the existing model and apply a state-dependent approximation model to estimate the truck queue length caused by short-term system oversaturation at marine terminal gates.

3. Methodology

Firstly, the study aimed to use a state-dependent approximation model developed by Yi, Tao, et al. (2021) to estimate truck queue length at the Apapa port terminal gate. Apapa Port Complex, also known as Apapa Quays, is the earliest and largest port in Nigeria. It is situated in Apapa, Lagos State, the commercial center of Nigeria. The Apapa port is well equipped with modern cargo handling equipment and personnel support facilities, making it cost-effective and customer friendly. It enjoys intermodal connections such as rail, water, and road. It boasts a four-wheel gate of about 8 metres for oversize cargoes, and this has given the port an edge over others in the handling of oversized cargoes.

The data for the study was collected from primary sources. Road traffic within the port, particularly at the exit points, was observed with the assistance of six field research assistants covering the three exits (4, 5, 6, and 7), while the researcher and the remaining research assistant monitored the queue length and observed the number of trucks that joined the queue on an hourly basis. However, a total of five thousand one hundred and two trucks were recorded in APC for a period of seven days. To estimate the queue formation and dispersion state of the calling trucks using a state-dependent approximation model, a multi-server (M/M/S) queuing model developed by Chen and Yang (2014) was adopted. It is assumed that:

i. The number of serves (S) is the number of marine gates, i.e., 4 at Apapa, including the emergency gate.
ii. The number of trucks arriving at the at the terminal gate per hour follows a poison distribution (M).
iii. The service time of the truck for each gate follows an exponential distribution (M).

Following the above assumption, the system utilization factor equation are as follows:

$$\rho = \frac{\lambda}{C} = \frac{\lambda}{\mu S} \qquad (1)$$

Where λ is the arrival rate of trucks i.e., the average number of trucks arriving per hour, C is the terminal gate service capacity, μ is the average number of trucks served in a gate per hour, and serves (S) is the number of marine gates.

Therefore, to estimate the average number of trucks, a multi-server (M/M/S) queuing model equation was adopted as follows:

$$L = \frac{P_0\left(\frac{\lambda}{\mu}\right)\rho}{S!\,(1-\rho)^2} = \frac{P_0\alpha^s\rho}{S!\,(1-\rho)^2} \quad (2)$$

Where, $\alpha = \frac{\lambda}{\mu}$ is traffic density of calling truck, P_0 is the probability that no trucks are in the queue i.e. Truck (T) = 0

$$P_0 = \sum_0^{S-1}\frac{\left(\frac{\lambda}{\mu}\right)}{n!} + \frac{\left(\frac{\lambda}{\mu}\right)}{S!}\left(\frac{1}{1-\rho}\right) = \sum_0^{S-1}\frac{(\alpha)^n}{n!} + \frac{(\alpha)^s}{S!}\left(\frac{1}{1-\rho}\right) \quad (3)$$

Based on questions 1 and 2, the average number of trucks in the queue, T, is a function of α, ρ and S. ρ is a function of α, and S. the average number of trucks in the queue T can be viewed as a function with only two variables α and S as follows:

$$L = \frac{P_0\left(\frac{\lambda}{\mu}\right)\rho}{S!\,(1-\rho)^2} = \frac{P_0\alpha^s\rho}{S!\,(1-\rho)^2} = \frac{P_0\alpha^s\frac{\alpha}{S}}{S!\,(1-\frac{\alpha}{S})^2} = \frac{P_0\alpha^s\frac{\alpha+1}{S}}{S!\,(1-\frac{\alpha}{S})^2} \quad (4)$$

Where,

$$P_0 = \sum_0^{S-1}\frac{(\alpha)^n}{n!} + \frac{(\alpha)^n}{S!}\left(\frac{1}{1-\rho}\right) = \sum_0^{S-1}\frac{(\alpha)^n}{n!} + \frac{(\alpha)^s}{S!}\left(\frac{1}{1-\rho}\right) \quad (5)$$

$$= \sum_0^{S-1}\frac{(\alpha)^n}{n!} + \frac{(\alpha)^s}{S!}\left(\frac{\alpha}{S-\alpha}\right) \quad (6)$$

To determine if oversaturated at time (t), that is queue steady state;

$$L = \frac{P_0\left(\frac{\lambda_t}{\mu_t}\right)s^tp_t}{S!\,(1-\rho)^2} = \frac{P_0\alpha_t{}^{s_t}p_t}{S!\,(1-\rho)^2} = \frac{P_0\alpha^s\frac{\alpha_t}{S_t}}{S!\,(1-\frac{\alpha}{S})^2} = \frac{P_0\alpha^s\frac{\alpha_t e^{s_t+1}}{S_t}}{S!\,(1-\frac{\alpha_t}{S_t})^2} \quad (7)$$

The estimation of the queue length for the queue formation State were determined by

$$\int_t^{queue\ formation} = \alpha_1(\alpha_t, S_t)In\,(t^1+1) + b_1(\alpha_1, S_t) \quad (8)$$

$$t' = exp\frac{l_{t-1} - b_1(\alpha_1, S_t)}{\alpha_1(\alpha_t, S_t)} \quad (9)$$

$$l_t = min\{l_t^{queue\ formation}, L_t\} \quad (10)$$

The estimation of the queue length for the queue dispersion state can be formulated as follows:

$$\int_t^{queue\ dispersion} = \alpha_1(\alpha_t, S_t)exp\,[b_2(\alpha_1, S_t)\,(t^1+1)] \quad (11)$$

$$t' = \frac{ln\left[\frac{l_{t-1}}{\alpha_2(\alpha_t, S_t)}\right]}{b_2(\alpha_t, S_t)} \quad (12)$$

$$l_t = max\{l_t^{queue\ dispersion}, L_t\} \quad (13)$$

5. Results and Discussion

Figure 1 shows the truck arrival pattern for the seven-day period of the study. From the analysis, a total of five thousand one hundred and two trucks were recorded within the study period. The arrival pattern shows that the peak period for the truck to arrive is between the hours of 22:00 and 5 a.m. in the morning. From this analysis, it implies that the road mode of transport at Apapa Port is always busy.

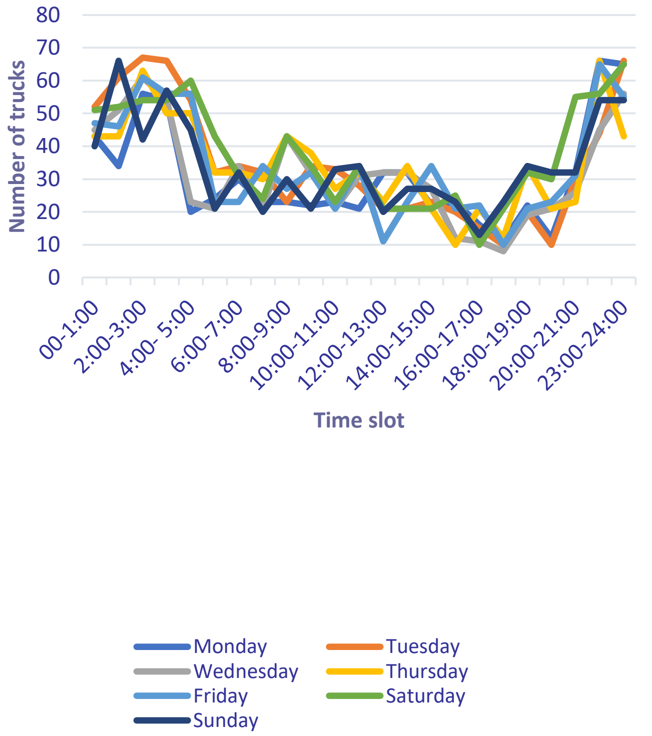

Figure 1: The analysis of the truck arrival pattern
Source: Authors Field work,2024

The arrival time and service time were measured as a result of the random numbers generated from two exponential distributions. The simulation time of 24 hours was adopted in the study. From the reconnaissance survey, the number of gates at Apapa Port is four: gate 4 (the emergency gate), gate 5, gate 6, and gate 7. The system utilisation factor (p) shows a value ranging from 0.75 to 0.95. The average truck-arrival rate (average number of trucks arriving per hour) is thirty-three trucks (33). The average service rate per gate (average number of trucks that can be served per hour per gate) is 11 trucks, while the total number of trucks served per day is sixty-five (65). The value of traffic density was set according to the number of gates because the system utilisation factor is equal to α/S and there are some constraints on the value of the system utilisation factor. Secondly, the system utilisation factor (ρ) should not be very small; otherwise, the steady queue length, i.e., the average number of trucks in the queue, will be very short and can be reached instantaneously. The results show that traffic density at all four gates is high. The result implies that the congestion at the gate is very high. The reason might be that the Nigerian port authority failed to implement the gate appointment system (GAS) method of managing truck arrivals into the port.

Table 1: truck arrive and queue situation at Apapa port complex

Number of gate (S)	System utilization factors	Average truck-arrival rate (λ)	Average service rate per gate	Total number of trucks served per day	Traffic density
4	0.75 to 0.95	33	11	65	0.75

Source: Authors Field work (2024)

From the queue simulation conducted, the simulation-based modelling results for queue formation and dispersion processes are presented in Table 2. The regression result analysis for queue formation state shows that it took less than an hour for the queue to reach its steady state, i.e., the critical point for the queue formation process, with a value of 0.6. with R square of 0.96. This implies that queue formation is less than an hour, meaning that queues are expected on a daily basis at the gate. The result on the queue dispersion state shows that it took a truck several hours to disperse or leave the gate. The critical point of the queue dispersion state shows a value of 40.16, which implies that it took a truck an average of two days to leave the terminal gate. Based on the results of the analysis, it was affirmed that the queue formation process and queue dispersion follow different pattern.

Table 2: Simulation results of queue formation process analysis

Queue formation process analysis							**Steady State**
S	α	a_1	b_1	R^2	$l_t^{queue\ formation} = a_1(\alpha,S)\ln(t+1)+b_1(\alpha,S)$	$L(\alpha,S)$	Critical point (t) (hour)
4	21	0.47	1.78	0.96	3.4312ln(t) + 8.1938	12.9232	0.6
Queue dispersion process analysis							
S	α	a_1	b_1	R^2	$l_t = max\{l_t^{queue\ dispersion}$	$L(\alpha,S)$	Critical point (t) (hour)
4	21	0.47	1.78	0.96	$322.21e^{-0.0032t}$	12.9232	40.16

Source: Authors Field work (2024)

6. Conclusion and Future Scope

Congestion at the marine terminal gate has become a serious issue for the Nigerian seaport. As a result of that, the present study used state-dependent approximation method to estimate the truck situation at Apapa terminal gate. The formation process and dispersion state of a truck were observed. From the result, it was found that a queue formation process took less than hour to formulate due to truck arrive rate recorded in the study. While queue dispersion took an average of two days. Going by the results, the study recommends that the Nigerian port authority should look at possible strategic measures, like the implementation of the gate appointment system (GAS) method, to reduce the number of trucks calling at the port in order to reduce peak-hour congestion at marine terminals.

Data Availability (Size 10 Bold)
none.

Conflict of Interest
Authors declare that they do not have any conflict of interest.

Funding Source
none

Authors' Contributions
Author-1 Wrote the first draft, review literature and conceived the study. Author-2 involved in protocol development, interpretation of model. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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