Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 4 July, 2022, pp.670 –679
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i4.5

Quay-Yard Operation Analysis of Port Container Terminals in Nigeria

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Article history: Received 27 June 2022; Revised form 8 July 2022; Accepted 8 July 2022; Available online 10 September 2022

Abstract
This paper presents significant measures to tackling berth occupancy and quay-yard operation problems. Case study was conducted on a port container terminal in Nigeria confidentially identified as 'Port A' in this paper. Hungarian assignment algorithm was used to reduce the total travel time of the yard trucks from an average of 6.4 minutes to 3.5minutes, while M/M/c/K queuing model was applied in scheduling the quay crane assignments. Results showed tremendous increase in quay crane rate, berth capacity and improved berth utilization. Also, for the reach stacker, the crane rate can be improved to 30 TEUs/hr at berth occupancy below 0.40 with TEUs factor of 1.4. These results imply that for Nigeria terminals operating with reach stacker crane, it is possible to improve the berth capacity without affecting the berth utilization of the terminal.

Keywords: Quay-yard operation, quay crane, berth capacity, berth occupancy, and utilisation.

1.0 INTRODUCTION

Maritime transport through shipping plays essential role in sustainable global trade and economic development around the world. It is one of the most economical means of traveling long distances with goods. Eco-friendliness, durability of goods and flexibility in delivering huge volumes of bulky goods are other advantages of maritime transport. In maritime transport, seaport container terminals are primary international supply chain mode and the links between the sea and the land. Seaport container terminals contains the seaside area, storage yard and landside. The seaside area is for loading and unloading container ships while the yard connects the seaside and the landside as it provides temporary storage for containers. The landside connects with the inland and is used for transporting import, export and trans-shipment containers. Therefore, seaport container terminal operation includes quay cranes, yard trucks, gantry cranes operation, and other operations management functions. Quay cranes (QCs) are used to load and unload sea going vessels while the gantry cranes operate as yard cranes (YCs), and they are used for loading and unloading yard trucks at the container storage yards.

The yard trucks (YTs) are mostly used for transporting containers between storage yards and berthing positions of vessels.

The earliness or tardiness in the delivery of trade goods is dependent on these seaport container terminal operations. With the increasing cargo throughput of seaports, truck congestion is common at seaport terminals, and it is one of the major challenges that affects the entire value chain. Truck congestion at the seaport terminals leads to shipping delays. Shortcomings as a result of congestion at a seaport terminal do not allow seaport handle too many cargo ships that need to dock at berth to unload or load. For example, in port terminals, carriers can arrive with 15,000 – 20,000 Twenty-foot equivalent units (TEUs) in one freight shipment and at such, many container ships must wait a long time, even more than two weeks outside the port at anchorage until a berth is available. These shipping delays due to congestions affects industries and businesses in terms of freight rates, higher demurrages and other extra operational costs. Strategies in tackling bottleneck operations at container terminals include good yard vehicles management, yard cranes and space managements. These strategies would guarantee efficient operation.

The aim of this study is to improve the productivity of port container terminals in Nigeria, while performance evaluation and applications of a number of significant measures to increase berth capacity are the objectives.

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2.0 LITERATURE REVIEW

One of the major challenges at seaport container terminals is how to always guarantee efficient turnaround of vessels, yard trucks and effective utilization of handling equipment. Therefore, operations research challenges at seaports are mostly concerned with problem settings that directly or indirectly affect the flow of containers within the ports[1]. Container ports that can serve several vessels simultaneously must reduce truck congestion so as to aim at high berth utilization rates. Koo et al [2] observed that containers are frequently transported between the container terminal and container yards, which may cause tremendous traffic problems if the yard trucks are not properly scheduled. Yard trucks (YTs) are used to transport containers between the berth and a storage yard (SY), and scheduling of these yard trucks is a logistic problem inherent in seaport container terminals. The more trucks that move within the same time, the more likely it is that traffic congestion could arise, which would cause delay in the truck cycle time [3], and ultimately results in shipping delays and delay in delivery of trade goods. Delivery operations can take long hours due to congestion [4] at container terminals. Congestion is a chronic problem in most ports, raising the cost of transport and hindering the growth of trade. Equally importantly, such delays in ports made trade movements erratic and unpredictable, obliging manufacturers, wholesalers and retailers to keep large stock [5]. Generally, long waiting time caused by congestion at the terminal is a concern to trucking companies due to the associated cost of delivery and demurrages. Scheduling of quay crane assignments and yard trucks to reduce congestions is of great importance for supply chain operations, as it determines to a great extent the distribution costs, as well as customer satisfaction [6]. According to Dias et al [7], the risks a port can pose to the organizations in its chain ranges from brief supply interruption to complete rupture. Due to problems with sea shipping and cargo handling at ports, there is a great risk that raw materials and finished products will be delayed in reaching customers. Providing solutions to these concerns had led many researchers to look at the effective container terminal management. In a comprehensive review, Kizlay and Eliiyi [8] observed that recent studies almost exclusively strive for a combined solution of quayside and yard side problems to minimize yard congestions as well as the travel effort of transport vehicles, while planning container handling operations. Also, Fazi et al [9] observed in the literature that operational decisions for inland shipping have received increased attention over the past decade. However, there are still rather few contributions on this topic when compared to the tactical and strategic aspects of the problem, and of course the real-world problem. After comparing the contributions and deficiencies among the research results in a review, Huiyun et al [10] proposed future valuable research directions such as efficient algorithm design, waiting time prediction, multi-link connection, and environmental cost pricing which provide reference for the continuous improvement of the truck appointment system. Chargui et al [11] opined that container transfer chain management should be carried out taking into consideration the maximum possible of environment interactions. They noted that integrated scheduling is a vital issue encountered by the majority of port container terminals in the world. Scheduling method for vessel, quay crane, worker and trucks deployment were proposed. The heuristic is integrated into a multi agent system as a scheduling agent and validated by a constraint programming model. However further studies were recommended on the topic in order to guarantee a near global optimization of the entire process. Hsu et al [12] also noted that optimizing collaborative operations for yard cranes (YCs) and yard trucks (YTs) is vital to the overall performance of a container terminal. The research suggested that a hybrid approach is found with the potential to outperform pure methods. Framework proposed by the authors for developing hybrid approaches for yard truck scheduling problem includes a load-balancing heuristic, a sequencing heuristic (or metaheuristic), and a simulation model. In a related research, Zhen et al [13] considered the coordination of the QCs scheduling and YTs scheduling problem to reduce the idle time between performing two successive tasks. Excellent integrated optimization that combines the above two processes avoid the efficiency loss due to mutual wait**.** To reduce the completion time of all containers from the vessel to their store location and of course reduce congestion at container terminals and guarantee efficient turnaround, Skaf et al [14] used mixed integer linear programming (MILP) and dynamic programming algorithm for single quay crane served by multiple yard trucks. Also, Stojakovic and Twrdy [15] used discrete-event simulation modelling to demonstrate that the allocation of the right number of yard trucks to quay cranes guarantees better productivity levels in the berth and yard subsystems. Also the hybrid model of Cahyono et al [16] incorporates the operations of quay cranes (QC), internal trucks (IT), and yard cranes (YC). Selection of storage positions in container yard (CY) and vessel bays in a dynamic modelling using finite state machine framework where each state machine is represented by a discrete-event system (DES) formulation was proposed. Results showed that the dynamical models are able to mimic the dynamic in the container terminal operations. Larson et al [17] presented model predictive controller that determines which combination of trucks, trains, and ships to use for transporting the containers and what routes should empty and full trucks use as one integrated problem. The proposed method successfully smooths out peaks in the needed number of trucks, even when it has a large number of trucks available. The results indicated an improved vehicle utilization. In a research for the optimal scheduling strategy of the yard truck, Hu et al [18] developed a multi-objective mathematical programming model through the pre-distribution of inbound container clusters and Outbound container cluster. The goal is to minimize the unloading voyage and achieve the shortest completion time to complete the loading and unloading of containers on multiple vessels. Pareto optimal solution used to transform the multi-objective mathematical model into a single objective provided better result than the Fuzzy membership function. Qin et al [19] investigated the joint scheduling problem of QCs, YTs, and YCs for the container unloading process in container terminals. The major contribution of the study was that detailed crane interference constraints of QCs, including non-crossing constraints, safety margin requirements and blockings at the initial stage, can be incorporated into both the mixed integer programming (MIP) and the constraints programming (CP) models of the 3-stage joint scheduling. However, the MIP model fails to be solved over realistic- sized instances because of a large number of variables and constraints. Its CP counterpart is more competent to produce feasible solutions within a practically reasonable computation time, but its solution quality, with varying gaps from 5.12 to 104.09%, is not acceptable. To reduce waiting time in container terminal, Nurcahyo et al [20] scheduled the arrival of container trucks using the Truck Turnaround Time method (TTTM). The method is the standard average time for trucks to fulfil a cycle starting from the truck going into the system until the process that must be completed by the truck. From the result obtained, implementation decreases the waiting time of the container truck. As a new strategy in port management, truck appointment system (TAS) was discovered to be one of the keys to improving operational efficiency. Truck appointment system is technological platforms aiming to coordinate truck flows at ports, by supporting the scheduling of truck arrivals and truck operations. Torkjazi et al [21] proposed TAS to minimize the impact of both terminal and drayage operations. When it comes to terminal operations, TAS seeks to evenly distribute truck arrivals throughout the day so that gates and courtyards are not overloaded. For transport of freight from port to destination, TAS will clearly consider the route of the truck and will endeavour to coordinate schedules that do not require the truck to deviate significantly from their original schedule. Caballini et al [22] also undertook optimal truck scheduling in a container terminal by using truck appointment system. Integer programming model was formulated to schedule the operations of trucks that have to pick up or deliver containers in a container terminal operating with a TAS. In a related research, Mar-Ortiz et al [23] proposed decision support system (DSS) in balancing the workload and determine the appointment quota for a container terminal working on a TAS environment. The DSS allows an efficient search of improved alternatives to configure the containers yard in order to minimize congestion. Cross-docking is a material handling and distribution concept in which products received at a terminal are immediately unloaded from inbound trucks, sorted and consolidated based on their destinations, and loaded directly into an outbound truck for delivery to customers who have little or no intermediate storage. Rijal et al [24] suggested cross-docking as a major operational decision at container terminal to reducing congestion. In related research, Tadumadz et al [25] opined that truck scheduling coordinates the loading and unloading processes of trucks competing for the timely processing at some terminal, for example, a cross-docking terminal or distribution centre. Therefore, integrated and workforce scheduling to accelerate unloading of trucks and reduce terminal congestion was suggested. Findings revealed that integrated planning can considerably increase the performance of truck scheduling in terms of total flow time and punctuality. However, He et al [26] considered uncertainty in scheduling since there are a lot of uncertain factors, such as the changes of shipping liner's plan, changes of weather, handling equipment, operational schedule failures and fluctuations. Such uncertainty also has to be adjusted through scheduling. A mixed integer programming (MIP) model and three-stage optimization algorithm was proposed to handle this problem. Integrated method for scheduling all types of container handling equipment - quay cranes, automated guided vehicles(AGVs) and yard cranes - in an automated container terminal was proposed by Luo et al [27] and the problem was formulated as a mixed-integer programming (MIP) model. The loading process was considered, during which containers are handled by YCs first, delivered by AGVs from the yard to quayside, and then loaded onto a container ship by QCs. The aim is to minimise the loading element of the berthing time of the ship and reduce container terminal congestion. This model optimized the operation of the container terminal by minimizing idle time and identifying the most effective solution for AGV, YC, and QCs. The results of this study show that handling large numbers of containers is time consuming and cranes tend to play a more important role in the terminal operations compared with AGVs. Aisha et al [28] demonstrated that optimization of container terminal layout in the seaport can improve the sustainability of port activities by decreasing the distance between the berth and interface points. Similarly, Aisha et al [29] suggested that improving intermodal container terminal layout will enhance port operations efficiency and facilitate smooth container flow. To provide needed capacity and efficiency for handling the increasing number of containers and reduce congestion, Gharehgozli et al [30] noted that current layouts have grown in size and are being equipped with state-of-the-art container handling systems, but suggested that performance, operational and investment costs, as well as social and environmental impacts are the main factors that can be used to choose a layout. In the past, Edokpia and Amiolemhen [31], and Adeke et al [32] have evaluated related congestion problems in the transport sector using other methods instead of Hungarian assignment model without a viable solution at sight. Analytical procedure suitable for use in performance evaluation of the quay-yard operational analysis is the Hungarian Assignment procedure. According to Stevenson [33], the Hungarian method assigns jobs by a one-for- matching to identify the lowest cost, task or work requirement solution. To the best knowledge of authors of this paper through the extant related literature reviewed, quay-yard operation analysis of container terminal had not been carried out using Hungarian assignment algorithm and queuing model for purpose of improving berth capacity and utilisation.

3.0 METHODOLOGY

Survey conducted at Port A enabled collection of data for performance evaluation of quay-yard operations of the port container terminal.

3.1 Data Collection

Data was collected from the port container terminal records and through direct observation within the scheduled availability. Data from the terminal record was in tandem with data collected through direct observation. The data points are the berths and stacking areas where data for berth occupancy, quay crane move, berth capacity and utilisation was collected.

3.2 Performance Evaluation of the Port Terminal

The parameters considered in the performance evaluation of the seaport terminal are berth capacity, berth occupancy, berth utilisation, berth throughput, terminal queue and waiting line characteristics.

3.2.1 *Berth Capacity, B_c*

Berth capacity is the amount of throughput a container terminal can handle in a year which is subject to the terminal's container stacking area, and of course the capacity of its quay. It also depends on the length of the quay and the capacity of the ship to shore cranes which are available. Berth capacity, B_C was evaluated with equation (1).

$$B_c = B_o N_c Q_{cm} S_A T_f \qquad (1)$$

B_o = berth occupancy
N_c = number of cranes attached to a vessel at berth.
Q_{cm} = quay crane moves per hour achievable.
S_A = scheduled availability or number of working hour/day.
T_f = TEU factor, which defines a factor for converting container to TEU. The standard container used worldwide as uniform measure of container capacity is Twenty-Foot Equivalent (TEU). Equation (2) defines the TEU factor.

$$T_f = \frac{T/h}{M/h} \qquad (2)$$

$T_f = TEU\ factor$.
$T/h = TEU\ per\ hour$.
$M/h = Moves\ per\ hour$.

3.2.2 *Berth Occupancy, B_o*

Berth occupancy is the time the berth is occupied by a vessel per total available time period. Berth occupancy was evaluated with equation (3).

$$B_o = \frac{B_V}{\sum_{i=1}^{n} S_A} \qquad (3)$$

B_V = time berth is occupied by a vessel.
S_A = scheduled availability or total available time period per day.

Equation (4) defines berth occupancy as the product of average number of vessels per week and the average turnaround time per vessel per berth,

$$B_o = \frac{N_{v/w}}{UL} \qquad (4)$$

$N_{v/w}$ = Average number of vessels per week
UL = Turnaround time per vessel per berth.

3.2.3 *Berth Utilization, B_u*

Berth utilization is a measure of a given terminal's operational efficiency given by the percentage of berth throughput to berth capacity as expressed in equation (5)

$$B_u = \frac{B_t}{B_c} \text{ x } 100 \qquad (5)$$

B_t is the berth throughput and B_c is the berth capacity.

3.2.4 *Berth Throughput, B_t*

Berth throughput is a measure of container handling activity of a terminal, which includes handling of imports, exports, empty containers and trans-shipment. Equation (6) defines it as the sum of total exports and total imports.

$$B_t = T_E + T_I \quad (6)$$

T_E = Total exports.
T_I = Total imports.

3.2.5 Maximum quay crane rate and service channels

Queue model with truncation or finite capacity (M/M/c/K) was used because it is an extension of M/M/c with Poisson arrival, blocked arrival, finite queue, servers and departure, where blocked customers is the new feature. This model was applied to get the maximum quay crane rate and service channel required to arrive at it. This model applies FIFS (First in -First served) service discipline, finite source of customers, and varying service channel. It is most appropriate for analyzing a container terminal since the vessel details are well known before arrival.

Probability there is no container at the terminal, ρ_o

$$\rho_0 = \left[\sum_{n=0}^{c}\frac{\rho^n}{n!} + \frac{\rho^c}{c!}\sum_{n=1}^{K-c}\left(\frac{\rho}{c}\right)^n\right]^{-1} \quad (7)$$

$$\rho = \frac{\lambda}{\mu} \quad (8)$$

where, ρ is utilization which is a measure of performance or productivity of a system, K is the number of vessels allowed in the system at any point in time (restriction), n is the number of customers in the system, c is the number of servers, λ is the arrival rate and μ is the service rate.

Probability of n containers at the terminal

$$P_n = \frac{1}{n!}\rho^n \rho_o \quad \text{for } 0 \le n \le c \quad (9)$$

Expected average queue length

$$E(m) = \frac{P_o\rho^c\left(\frac{\rho}{c}\right)}{c!(1-\frac{\rho}{c})^2}\left[1 - (\frac{\rho}{c})^{K-c+1} - (1-\frac{\rho}{c})(k-c+1)(\frac{\rho}{c})^{K-c}\right] \quad (10)$$

Expected number of containers at the terminal

$$E(n) = E(m) + c - \rho_o \sum_{n=0}^{c}\frac{(c-n)\rho n}{n!} \quad (11)$$

Expected average waiting time W_T= E(v) - $\frac{1}{\mu}$ (12)

where, expected average total time $E(v) = \frac{E(n)}{\lambda(1-p_K)}$ (13)

By assigning the quay crane speed as the arrival rate and the total speed of the horizontal truck and yard crane as the service rate, we solved for the waiting time and average total time to service the cranes attached to the ship using reach stacker as the yard crane. The crane speed is the average speed of the servicing crane operators without delays, and the horizontal speed is dependent on the design layout and transfer policies of the terminal., thereby giving the Quay Crane rate, QCR as:

$$\text{QCR} = (\text{Waiting time} + \text{Average service time})^{-1} \quad (14)$$

In the quay crane rate, QCR, analysis was done using queuing theory to solve the average waiting time for n number of containers and total time to complete loading and unloading them. The crane rate was equated to arrival rate and the number of customers equated to the number of containers at berth. For ease of computation, an excel program was created on MS Excel as a computation tool for solving the queuing equation (M/M/c/K) for up to twenty-one channels.

In the computation, the point where the average total time of service (waiting time plus the service time) cannot reduce any further gives the optimal service per TEU and hence the optimal number of vehicles needed to optimal service time. The yard crane also serves other operations; so, the server utilization, ρ was analysed, this gives an idea of the workload on a particular server.

3.2.6 Minimization of the truck turnaround and transfer time using Hungarian Assignment Algorithm

3.2.6.1 Model formation

The following parameters were taken into consideration for the model formation: Quay crane rate (QCR), truck turnaround time (T_t), waiting time (W_t), yard crane rate (Y_{ct}) and transfer time (T_{rt}) given by $T_{rt} = \frac{Speed}{Distance}$. For efficient operation at the terminal, quay crane rate has to be maximized and in turn minimize truck turnaround and transfer time.

Therefore,

$$\text{Maximization, QCR} = (W_t + T_{rt} + Y_{ct})^{-1} \quad (15)$$

Subject to constraints
$W_t \ge 0$
Speed ≤ 30Km/h
Distance ≤ 0.41Km
Channels ≤ 21

$$\text{Minimization, } T_t = (W_t + T_{rt} + Y_{ct}) \quad (16)$$

Subject to Constraints
$W_t \ge 0$
Speed≤ 30Km/h

Distance ≤ 1.8Km
Channels/lanes ≤ 21
Minimization, Trt = $\sum_{i=1}^{m}\sum_{j=1}^{n} Txij$ (17)

Subject to Constraints

$\sum_{i}^{n} Tx_{ij} = ai,\ \ i = 1,2, \dots \dots n(quay\ Constraint)$

$\sum_{j}^{m} Tx_{ij} = bj,\ \ i = 1,2, \dots \dots m(Stack\ Constraint)$

$X_{ij} \geq 0$ for all i and j

The berths were labelled 1,2,3 and the stacking area labelled A, B, C. The time in minutes spent by yard trucks in moving container from the berths to the stacks are presented in 3 x 3 matrix and allocations found by using Hungarian Assignment Algorithm. (See Appendix I).

4.0 RESULTS AND DISCUSSION

After performance evaluation, terminal berth capacity for varying berth occupancy, quay cranes and 12moves/hr are presented in figure 1 as generated from equation (1) and berth utilisation for a berth throughput of 397,276 TEUs, 12 moves/hr with varying berth occupancy and quay cranes is presented in figure 2 as generated from equation (5).

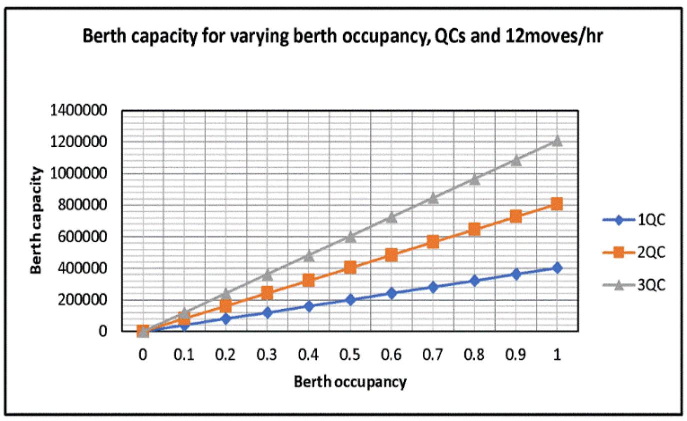

Figure 1: Plot of berth capacity against berth occupancy

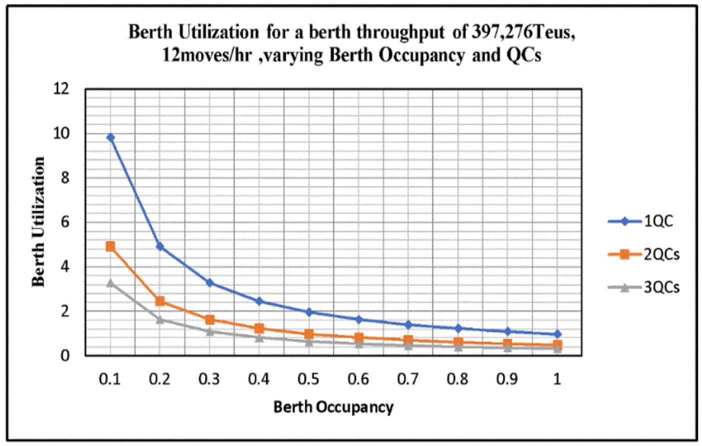

Figure 2: Plot of berth utilization against berth occupancy

Results showed that increase in the number of quay cranes can increase berth capacity while high berth occupancy indicates restriction of vessel to be served and congestion. But low berth occupancy can also indicate underutilization of port container resources.

The more the quay cranes attached to a berth, the more the productivity at the berth as vessels leave the berth earlier.

After performance improvement, berth capacity increased significantly for a number of quay crane attached, and as well berth utilisation was significantly reduced. Attaching 2QC instead of 3QC to a berth was found to be optimal at varying berth occupancy which suggests that it is less expensive to improve the quay crane rate through operations management measures than increasing the number of the cranes. To achieve the results, the total travel time of the yard trucks from quay to yard was reduced from 6.4 minutes to 3.5minutes to improve the crane rates at the quay and yard.

Also, scheduling the crane assignment increased the quay crane rate, reduced berth occupancy, and increased berth capacity. Quay crane rates and utilization (performance) achievable for a number of quay cranes attached to a berth and varying channels as generated from equation (15) are presented in figures 3-5.

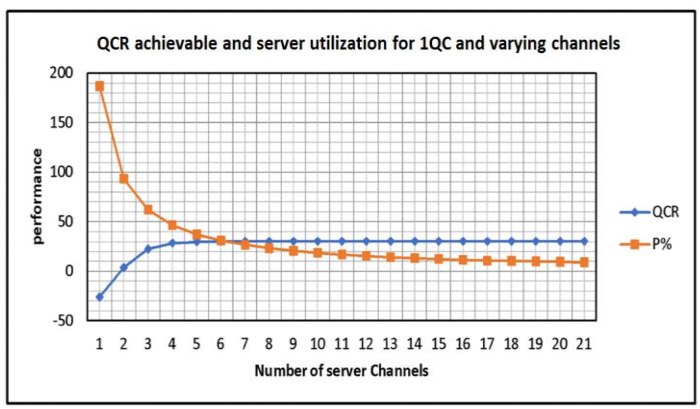

Figure 3: Plot of QCR and Utilization (Performance) for 1QC and Varying Channels

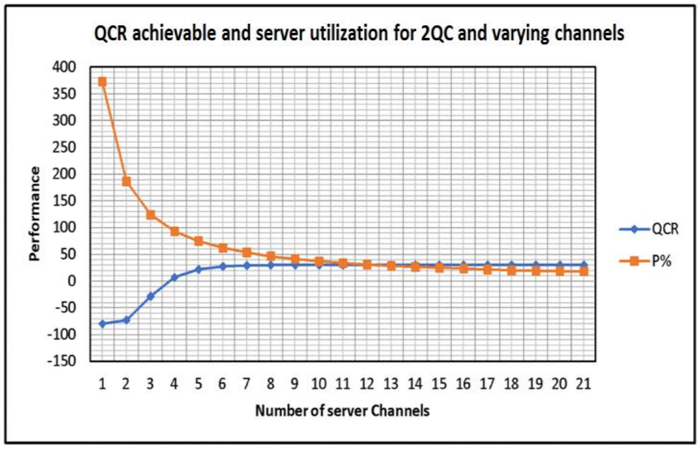

Figure 4: Plot of QCR and Utilization (Performance) for 2QC and Varying Channels.

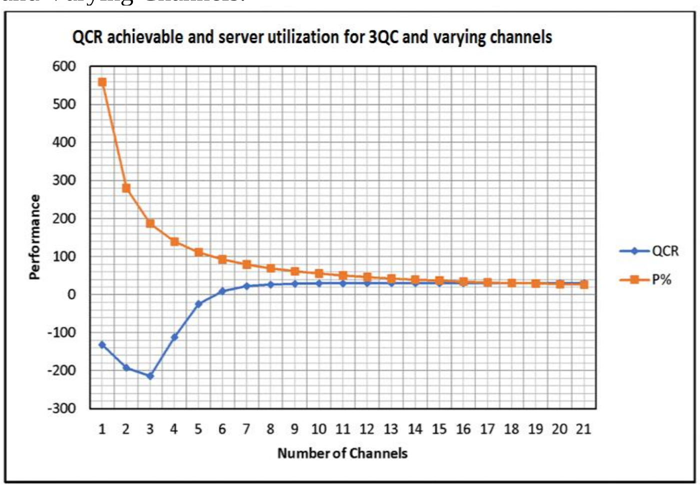

Figure 5: Plot of QCR and Utilization (Performance) for 3QC and Varying Channels

Again, for a terminal operating with reach stacker crane; this work shows that the quay crane rate can be improved to 30 TEUs/hr and berth occupancy below 0.40 for a terminal with a TEUs factor of 1.4. These indicates that for Nigeria terminals operating with reach stacker crane, it is possible to improve the berth capacity without affecting the berth utilization of the terminal.

5.0 CONCLUSION

Quay-yard operation analysis of port container terminals in Nigeria using 'Port A' as a case study has been carried out. The study has provided useful information concerning ports operational performance in Nigeria which are directly related to quay-yard activities. The crane rate and yard truck travel time which are the major performance indices of a terminal was used to evaluate the terminal capacity and utilization for varying berth occupancy and several quay cranes. The average quay crane rate of 12 moves/hr achieved by the terminal which is below 25 moves/hr achieved by standard port container terminals is an indication for underperformance. To improve the berth capacity, utilization and occupancy, the quay crane rate is either improved or the number of quay crane is increased per berth. This study shows that it is less expensive through operations management measures to improve the crane rate than the number of cranes. Queuing model for multi-arrival, a multi-service system (M/M/c/K) was applied to schedule the crane assignment using the no-pooling policy of transfer system to improve the quay crane rate, berth occupancy, capacity and utilization of the terminal. The yard truck travel time which is critical to crane rates was reduced using Hungarian assignment algorithm. Results obtained showed a significant reduction in berth occupancy and increase in berth capacity. Again, for a terminal operating with reach stacker yard crane; this work shows that the quay crane can be improved to 30 TEUs/hr and berth occupancy below 0.40 for a terminal with a TEUs factor of 1.4. These results imply that for Nigeria terminals operating with reach stacker crane, it is possible to improve the berth capacity without affecting the berth utilization of the terminal.

The valuable contribution of this work would lead to cost effectiveness and efficient port container terminal operation through quality services to customers (ship operators, ship owners, importers and transport operators) emanating from reduced ship turnaround time, truck turnaround time, container dwell time and equipment availability.

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APPENDIX I

Hungarian Assignment algorithm for the Seaport Container Terminal

Berths were labelled 1,2,3 and the stacking area labelled A, B, C. The time in minutes spent by yard trucks in moving container from the berths to the stacks are presented in 3 x 3 matrix below and allocations found by using Hungarian Assignment Algorithm.

Berth/Stack	**A**	**B**	**C**
1	1.05	1.60	2.14
2	1.60	1.05	1.60
3	2.14	1.60	1.05

Row reduction

Berth/Stack	A	B	C
1	0	0.55	0.55
2	0.55	0	0.55
3	1.09	0.55	0

Column reduction

Berth/Stack	**A**	**B**	**C**
1	0	0.55	1.09
2	0.55	0	0.55
3	1.09	0.55	0

m =3 and since number of lines =3, there is optimal allocation

Berth/Stack	A	B	C
1	0	0.55	0.55
2	0.55	0	0.55
3	1.09	0.55	0

Assignment

Berth 1- Stack A = 1.05mins
Berth 2- Stack B = 1.05mins
Berth 3- Stack C = 1.05mins

Lead time = 3.15mins < 3(2.14mins) =6.42mins
For cases where a stack is filled up, a dummy value is assigned and therefore containers cannot be assigned to that stack from any berth.
For filled stack A
Row reduction

Berth/Stack	A	B	C
1	∞	1.60	2.14
2	∞	1.05	1.60
3	∞	1.60	1.05

Berth/Stack	A	B	C
1	∞	0	0.54
2	∞	0	0.55
3	∞	0.55	0

Column reduction

Berth/Stack	A	B	C
1	0	0	0.54
2	0	0	0.55
3	0	0.55	0

m =3 and since number of lines =3, there is optimal allocation

Assignment: Stack A cannot be assigned, but berths must be assigned to other stacks. So, either stack B or C must be assigned to 2 berths.
Berth 1- Stack B = 1.6mins
Berth 2- Stack B = 1.05mins
Berth 3- Stack C = 1.05mins
lead time = 3.7mins < 3(2.14mins) = 6.42mins

For filled stack B

Berth/Stack	A	B	C
1	1.05	∞	2.14
2	1.60	∞	1.60
3	2.14	∞	1.05

Row reduction

Berth/Stack	A	B	C
1	0	∞	1.09
2	0	∞	0
3	1.09	∞	0

Column reduction

Berth/Stack	A	B	C
1	0	0	1.09
2	0	0	0
3	1.09	0	0

m =3 and since number of lines =3, there is optimal allocation.

Assignment: Stack B cannot be assigned, but berths must be assigned to other stacks. So either stack A or C must be assigned to 2 berths.

Berth/Stack	A	B	C
1	□	0*	1.09
2	0	0*	□
3	1.09	0*	□

Berth 1- Stack A = 1.05mins
Berth 2- Stack A or C = 1.60mins
Berth 3- Stack C = 1. 7mins 05mins
lead time = 3. <6.42mins

For filled stack C

Berth/Stack	A	B	C
1	1.05	1.60	∞
2	1.60	1.05	∞
3	2.14	1.60	∞

Row reduction

Berth/Stack	A	B	C
1	0	0.55	∞
2	0.55	0	∞
3	0.54	0	∞

Column reduction

Berth/Stack	A	B	C
1	0	0.55	0*
2	0.55	0	0*
3	0.54	0	0*

m =3 and since number of lines =3, there is optimal allocation.

Assignment: Stack C cannot be assigned, but berths must be assigned to other stacks. So, either stack A or B must be assigned 2 berths.

Berth/Stack	A	B	C
1	□	0.55	0*
2	0.55	□	0*
3	0.54	□	0*

Berth 1- Stack A = 1.05mins
Berth 2- Stack B = 1.05mins
Berth 3- Stack B = 1.60mins
Lead time = 3.7mins < 6.42mins