The optimization of container stacking process under the impact of synchronization of seaport container terminal operations

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Abstract

Efficient stacking strategy in a container terminal is an essential task affecting competitiveness in many seaports, especially because this singular action may influence many of the conflicting objectives, like minimizing the reshuffles (unproductive moves) and number of future relocations of containers in storage yard and maximizing the yard density and stacking area capacity utilisation. Any delay or deficiency in the synchronization and sequencing of daily operations and activities between seaside and landside of terminal will affect the stacking process in the container yard and may lead to the interference of terminal operations and lack of control in the scheduling of concurrent operations and activities during the management of inbound and outbound containers.

In this paper, we model a seaport container terminal as a queuing system to obtain the service level parameters. A multi-server queue in tandem consisting of two stages was considered, the first stage being the relations between handling-off process and transportation process, the second stage being the relations between transportation process and stacking process. Also, we consider twenty different scenarios of container stacking inside a container terminal to evaluate the performance of the queuing model. These scenarios vary from each other in terms of quantities of containers, durations of stay for the vessels in the seaport and number of equipments (quay cranes, yard trucks and yard cranes) that are used to perform the operations.

Experimental results were obtained from using the queuing model to evaluate the performance of the seaport container terminal operations, and to understand the behavior and characteristics of container stacking problem in a container yard. In general, experimental results show how increase in the number of service centers (yard trucks in the first stage and yard cranes in the second stage) affect the total waiting time of containers in the queue, the total time for containers that are serviced in the system and the average utilization of the system. Furthermore, we determined the optimal number of equipments to be are used in service to achieve a given service level.

Keywords
Container stacking, Reshuffle, Queuing theory, Multi-server queues in tandem.

1. Introduction

Most container terminals want to improve and develop the container stacking system and the usage of storage space in the yard area, in order to facilitate accessibility to the containers in the stacking area and to minimize the reshuffles (unproductive moves) due to inappropriate storage location and stacking orders of containers. In stacking area, the containers are stacked within a set of blocks, and they are usually arranged and classified according to a number of factors: their destination (inbound, outbound, and transshipped), loading status (FCL, LCL and empty), type of goods (reefer, dangerous …etc) and container size (TEU, FEU, non-standards). Many seaports try to manage their container terminals efficiently, and they apply different stacking strategies to improve the efficiency (minimizing unproductive movements) and to increase the productivity (throughput) of container terminals. The best stacking strategy is usually the one that optimizes operational productivity by maximizing the utilization of storage space and minimizing the number of unproductive moves within the blocks and/or the bays.

When the inbound containers arrive at the container yard, they are initially stacked for temporary storage, but actually during the dwelling of containers for a certain period in the stacking area, the containers are moved within the same blocks (intra-block movements or remarshalling) or within the same bays (intra-bay movements or premarshalling) to minimize the number of future relocations or future unproductive moves. That means the objective of remarshalling and premarshalling is to reshuffle the export containers into a proper arrangement within the same blocks and within the same bays to increase the efficiency of the loading operation.

The sequence of operations and activities between seaside and landside of terminal affects the stacking process in the container yard. Therefore, one of the main challenges in the container terminals concerns the interference of operations, i.e. there are a lot of tasks, functions and sub-operations that need many types of equipment, cranes, trucks and vehicles to deal with the flow of containers through seaport terminals.

Managing or scheduling the daily operations and activities of a seaport container terminal is a complex process. Therefore, any delay in the sequence of operations, functions, events, and activities of seaport container terminal leads to deficiency in the scheduling and management of terminal operations. Furthermore, the delays increase the dwell time of containers (empty and fully loaded) at seaport terminal, and incur additional expenditure, especially if one takes into account the waiting time of containerships and equipment and the occupation of containers in the yard area. The delays also lead to reduced productivity (throughput) of seaports and reduce the possibility of demand fulfillment in desirable time. Solutions proposed to container stacking problem have used are of different types including heuristic algorithms, simulation models mathematical programming.

Chen and Chao (2004) formulated a mathematical model with time-space network to deal with the storage space allocation problem for export containers in a container yard. The proposed model was applied at the Port of Kaohsiung in Taiwan to evaluate yard planning with the sort and store strategy. It was used to minimize the total assignment cost, and applied to many adjustment strategies (adjustments in assignment cost, arrival dates of containers and demands of ground-slot sets) to optimize the usage of ground-slot sets in terms of time and space and solved the model using CPLEX, through an application of the network framework. Ng and Mak (2005) developed a mixed integer programming model to address the yard crane scheduling problem in performing a given set of handling jobs (loading/unloading) with different ready times. The proposed model seeks to minimize the sum of job waiting times (completion time, ready time and handling time). A branch and bound algorithm was proposed to solve the scheduling problem optimally, and it found the optimal sequence for most problems of realistic sizes.

Chu and Huang (2005) compared three different handling systems in the seaport container terminal [Straddle Carriers (SC), Rubber-Tyred Gantry crane (RTG), and Rail-Mounted Gantry crane (RMG)] when determining the container terminal capacity. They discussed and analyzed the critical factors which affect the procedure of determining terminal capacity such as yard size, the adopted yard handling system, yard crane dimensions, container transshipment ratio and the average container dwell times in the container yard. They found that the general model can be very useful and helpful for container terminal planning with regards to the selection of handling technology, site location or proposed service expansions. Schmidt et al (2005) developed a computer model to improve the efficiency of operations and activities of small and medium sized ports or container terminals and to resolve the operational problems. The model (electronic Terminal Planning Board-TPB) enables seaport authorities in re-engineering of terminal layout, selection of cargo handling equipment and working methods to reduce manpower, minimize travelling distance and time by using different routes, equipment and arrangements of slot spaces to increase terminal capacity, terminal throughput and terminal efficiency. Furthermore, the model affords potential planning opportunities and operationally feasible results and improves the efficiency of the container terminals by increasing the cargo throughput, reducing the turn-a-round time of vessels and other vehicles as well as the unproductive times on the terminal.

Leong and Lau (2007) solved a job scheduling problem for handling, transportation and stacking equipments [Quay Crane (QC), Prim-Mover (PM), Yard Crane (YC)] in a container terminal. They formulated a mathematical model and solved it using a heuristic to minimize the completion time of the QC sequence, traveling time of PM, and cycle time of YC. Computational experimental results showed that the algorithm yields the optimal solution for the problem and leads to better relationship between the Gross Crane Rate (GCR) and the available equipment (PM and YC). Froyland et al (2008) studied the problem of managing containers exchange facility with multiple semi-automated Rail Mounted Gantry cranes (RMGs) in the landside area at the Port Botany Terminal in Sydney. They proposed an integer programming model with heuristic solution consisting of three stages (the scheduling of cranes, the control of associated short-term container stacking, and the allocation of delivery locations for trucks and other container transporters). The solution was shown to be effective and the framework helped to minimize the size of the required straddle carrier fleet, and the heuristic was able to obtain an optimal solution to the problem, which includes scheduling the RMGs, assigning the short-term positions of containers, and determining truck bays to be used.

Salido et al (2009) focused on the container stacking problem and developed a domain-dependent planning tool based on a heuristic to minimize the number of reshuffles of containers. The proposed planning tool was used to organize all the containers in the yard-bay according to their departure time. They concluded that the proposed heuristic could find the optimal solution to minimize the relocations of containers in a container yard and it finds the best configuration of containers in a bay to avoid further reshuffles.

Mak and Sun (2009) proposed a new hybrid optimization algorithm to address the problem of scheduling multiple yard cranes in a container yard, and to minimize the sum of the completion times of the yard cranes. The proposed algorithm consists of combining the techniques of genetic algorithm and Tabu search method (GA-TS). The researchers formulated a mixed integer program mathematical model to minimize the summation of container ready time, the handling time, the yard crane travelling time and the waiting time of yard cranes due to inter-crane interference. The computational results show that the new algorithm (GA-TS) is an effective and efficient means to solve the problem and gives a reasonable solution within limited time, also provides cost-effective solutions on average 20% better than that found by genetic algorithm (GA) only.

Kefi et al (2010) suggested and developed two models to optimize the container stacking activity within maritime or fluvial ports. The basic model is based on an uninformed search algorithm and it allows simulating and solving the container stacking process while the extended model is based on an informed search algorithm, and it allows optimizing this process. They compared the results that were obtained by using the two proposed models and found that the latter performs much better than the former, and the heuristics are better choice to solve the combinatorial optimization problem such as the container stacking problem.

Vidal and Huynh (2010) built a multiagent-based simulation model to simulate and analyze the behavior of the yard cranes, and to evaluate the collective performance of the system. The proposed model is used to minimize the distance between the cranes and trucks, or to minimize the total waiting time (including the time it takes a crane to arrive at bay where the truck is parked and the time it takes the crane to perform both re-handling and delivery moves). They stated that the model provides a powerful tool to assess the performance of yard cranes in the seaport container terminals. Asperen et al (2010) developed a discrete-event simulation model using Java programming language to evaluate the performance of stacking strategies and stacking rules in a container terminal. The proposed simulation consists of two major components: the generator program and the simulator program. The generator program creates arrival and departure times of the containers, and the output of the generator is a file that contains the ship arrivals, details of the containers to be discharged and loaded and the specification of the destination of each container. The simulator program reads the output of the generator and performs the stacking algorithms. They found that the simulation model can capture the amount of detail required and that it is flexible enough to support the evaluation of the stacking rules.

Lee et al (2011) addressed the integrated problem of bay allocation and yard crane scheduling in transshipment container terminals. They developed a mixed integer programming model to minimize the total cost, including yard crane cost (setup and travel costs of yard crane) and task delay cost. Given the complexity of the problem, they proposed a simulated annealing (SA) heuristic to find near optimal solutions. Numerical experiments show that the SA heuristic show promises of handling the integrated problem.

Wang and Kim (2011) suggested a heuristic to address the Quay Crane (QC) scheduling problem, and proposed a mathematical model to estimate the impact of a QC schedule on the workload of yard cranes in each block of container terminal. The model is used to minimize the total completion time, the total expected delay time due to the interference of QCs, traveling time of QC and excessive allocation of blocks to each QC in addition to the make-spam of QCs. Numerical experiments were used to test the performance of the heuristic and they are showed reasonable performance for the application to practices.

Sharif et al (2012) focused on the Inter-Block Yard Crane Scheduling or Deployment Problems in a marine container terminal, and provided an agent-based approach to assign and relocate yard cranes among yard blocks based on the forecasted work volumes. The proposed approach was used to find the effective schedules for yard cranes and to minimize the percentage of incomplete work volume. They applied many strategies to assign the cranes among blocks at the beginning of a planning period based on the work volume forecast. Results show that the proposed model can find an excellent solution in short time for a range of work volume conditions with high variation and in medium condition, all work can be finished within planning period. In heavy and above capacity conditions, the percentage remaining incomplete is less than or equal to 1% and within 3% of the optimal respectively.

Sriphabu et al (2013) developed a simulation model using Arena to determine the time of yard crane that is spent to lift a container and to transfer it to the containership. They developed a genetic algorithm (GA) to minimize the total lifting time and to increase the service efficiency of the container terminal. Experimental results obtained from the model by using the proposed GA, and First-in, First-Storage (FIFS) rule or strategy indicated that the simulation model based on GA is more efficient than the simulation model based on FIFS rule. The efficiency difference increased by up to 34.78% and the average was 25.47% for all experiments.

Borjian et al (2013) studied the Dynamic Container Relocation Problem (DCRP) and proposed a two-stage stochastic optimization model to minimize the number of container relocation moves in a container yard with continual arrival and departure. The computational results indicate that the stochastic optimization model can achieve the optimal solution of the problem and it provides solutions closer to the reality of port operations.

Jovanovic and Voß (2014) presented a chain heuristic approach to optimize the Blocks Relocation Problem (BRP), and to minimize the total number of moves. The proposed heuristic was used to decide where to relocate a single block taking into account the properties of the block that will be moved next. They compared the results obtained by using the proposed heuristic to those of several existing methods of on test data of a wide range of sizes and found that the chain heuristic achieved the best results in almost all of the tested cases.

In this paper, we study the container stacking problem in seaport container terminals, focusing on the optimization resources of stacking process under the impact of the synchronization and sequence of daily operations and activities between seaside and landside of terminal under a given service level using queuing theory.

This paper is organized as follows: section (2) describes container stacking problem in a container terminal. In section (3) we formulate the model as a queuing system. Next is section (4) where we present numerical experiments for a case study and discuss the experimental results. Finally, in section (5) we conclude this study.

2. Problem description

When inbound containers arrive at container yard, they are initially stacked in the stacking area for temporary storage. Usually, the stacking area is made up of many blocks, and the containers are arranged in each block by rows (stacks), columns (bays) and tiers. At the container yard, the containers are lifted-off from yard trucks by yard cranes, and they are stacked in several blocks in 3D arrays. Each block can handle a mass of containers in one block, and the yard crane is used to move the containers within the same block or within the same bay. The movement of containers within the stacking area (within blocks or bays) is called re-handling, whereas the movement of containers from the bays to the vessels or the containerships is called retrieving. A schematic diagram of a typical container terminal is shown in the Figure (1).

Container stacking problem is concerned with how to find the suitable storage locations for the inbound containers within the blocks to minimize the future relocations. The initial locations of containers (temporary locations) may be the permanent storage locations during the full period of storage or may change to some new locations within the same block. In seaports, container yard configuration and layout are determined by the type of stacking strategy that is used to store, stack, arrange and manage the containers within the yard. There are different stacking strategies that are applied in seaports and depots like: segregation strategy, scattering strategy, category strategy and residence time strategy. These strategies are used to achieve the efficient usage of storage area, and to avoid the unproductive moves of containers and yard cranes.

Delay due to the sequencing of operations in the seaport container terminal may lead to deficiency in the scheduling and management of terminal operations in the flow of containers between quay side and yard side. Therefore, it will affect the stacking process in the container yard. Also, deficiency in the synchronization and sequence of daily operations and activities between seaside and landside of terminal may affect the stacking process in the container yard and lead to interference of terminal operations and lack of control when scheduling concurrent operations in inbound and outbound flows of containers.

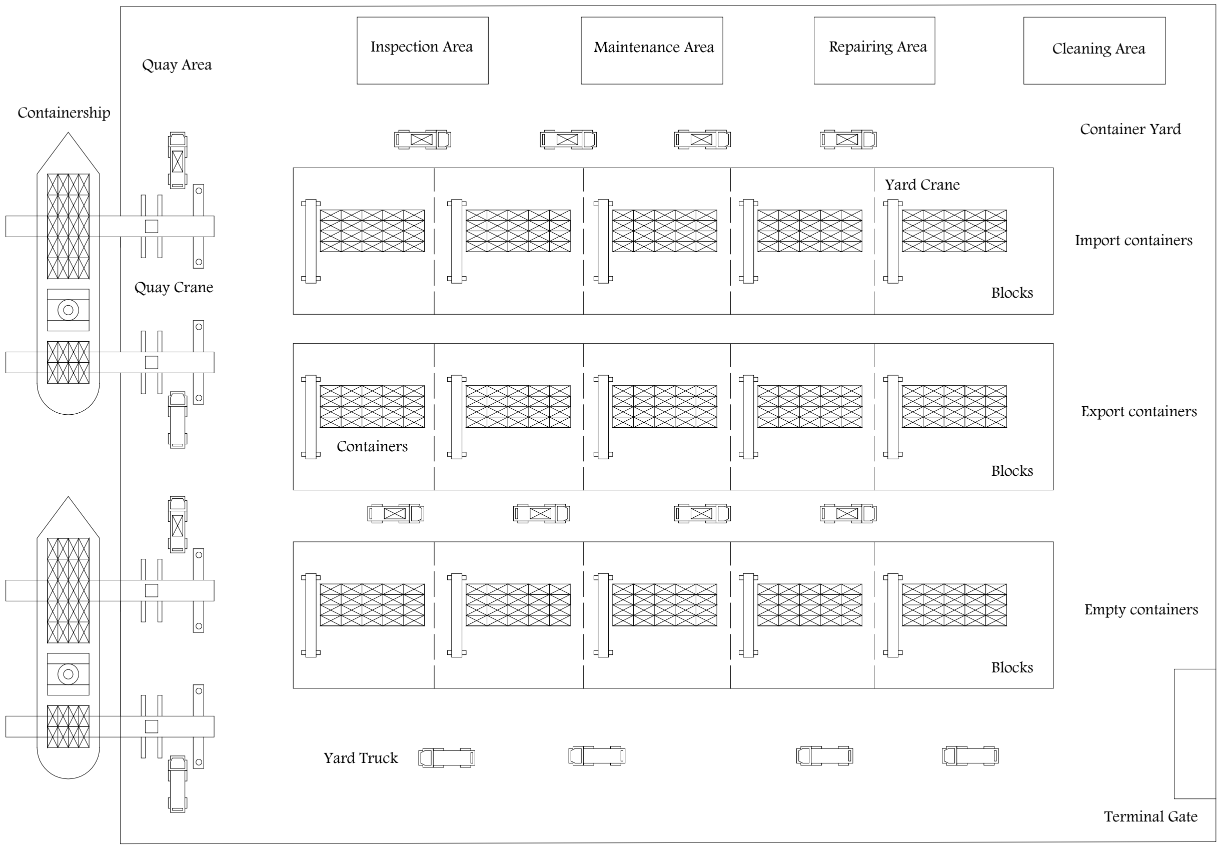


Figure 1: A schematic layout of a container terminal.

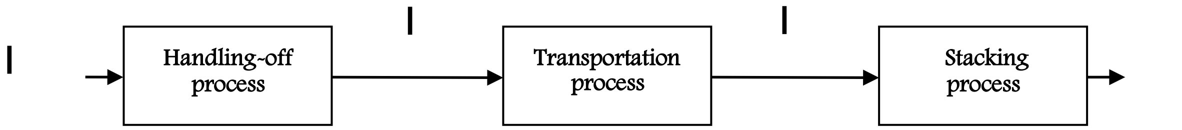
3. Mathematical model

In this section, the problem can be modeled as a queuing system to understand the behavior and characteristics of container stacking problem under the impact of synchronization of seaport container terminal operations. When the inbound containers arrive at quay side, they are served by quay cranes. i.e. The containers are unloaded from containership by cranes, and then they are moved from quay side to the container yard by trucks. At stacking area in container yard, the yard cranes are used to stack the containers in many blocks.

Usually, the arrival containers or the inbound containers at seaport have arrival rate λ. The first stage is the relation between handling-off process and transportation process. i.e. quay cranes removes the inbound containers at the arrival rate, λ and the yard truck, though has a service rate of capacity μ_1, but moves the containers away at a rate which is also λ (conservation of flow, $\mu_1 \geq \lambda$). The second stage is the relation between transportation process and stacking process with the arrival rate λ of containers from yard trucks and the service rate of the yard cranes stacking the containers is μ_2. For each stage, j, the average inter-arrival time of the containers can be expressed as $1/\lambda$. The average inter-service time per server per container can be expressed as $1/\mu_j$. The utilization factor of the system for each stage is the ratio between the arrival rate and service rate, and can be expressed as $\rho_j = \frac{\lambda}{\mu_j}$ or $\rho_j = \frac{\lambda}{s * \mu_j}$ for a multi-server system, where s is the number of servers in the system.

Actually, in queuing system, there are one or more servers that provide service to the arriving customers. In our case, the customers are containers and the servers are quay cranes, yard trucks (vehicles) and yard cranes. We model the sequence of operations inside seaport like queues in tandem, i.e. multi-server queues in tandem, the input of each queue except the first (when the inbound containers arrive at quay side) is the output of the previous queue. The tandem system in our case consists of two stages, the first stage being the relation between handling-off process and transportation process, the second stage being the relation between transportation process and stacking process. In this queuing system (a multi-server queuing model), we assume the arrivals follow a Poisson distribution at an average rate λ containers per unit time (hour). Also we assume the service times are distributed exponentially with an average μ containers per unit time (hour). The service in the system follows a queue discipline of First-in, First-out/First-come, First-served (FIFO/FCFS), and all servers in each stage are assumed to perform at the same rate, μ. Figure 2 represents the queues in tandem system.

Fig. no. (2) the queues in tandem system at a container terminal.



The probability that there are no containers are in the system P_0 and can be expressed as:

$$P_0 = \left[\sum_{n=0}^{n=s-1} \frac{\left(\lambda/\mu\right)^n}{n!} + \frac{\left(\lambda/\mu\right)^s}{s!} * \left(\frac{1}{1-\rho}\right) \right]^{-1} \quad \ldots..(1)$$

Where the average utilization of the system multi-server queues in tandem is equal to $\rho = \frac{\lambda}{s * \mu}$

The probability that n containers are in the system P_n and can be expressed as:

$$P_n = \frac{\left(\lambda/\mu\right)^n}{n!} P_0 \quad \ldots..(2) \quad \text{for } n \leq s \;, \quad P_n = \frac{\left(\lambda/\mu\right)^n}{s! * s^{n-s}} P_0 \quad \ldots..(3) \quad \text{for } n > s$$

Where n is the number of arrivals (containers), and s is the number of servers in the system.

The average number of containers waiting in the queue or line L_Q can be expressed as:

$$L_Q = \frac{P_0 \left(\lambda/\mu\right)^s \rho}{s!\,(1-\rho)^2} \quad \ldots..(4)$$

The average time of container spent waiting in the queue or line W_Q can be expressed as:

$$W_Q = \frac{L_Q}{\lambda} \quad \ldots..(5) \qquad \text{or} \qquad W_Q = \frac{P_0 \left(\lambda/\mu\right)^s \rho}{s! * \lambda\,(1-\rho)^2} \quad \ldots..(6)$$

The average time of container spent in the system, including service W can be expressed as:

$$W = W_Q + \frac{1}{\mu} \quad \ldots..(7) \qquad \text{or} \qquad W = \frac{P_0 \left(\lambda/\mu\right)^s \rho}{s! * \lambda\,(1-\rho)^2} + \frac{1}{\mu} \quad \ldots..(8)$$

The average number of containers in the service system L can be expressed as:

$$L = \lambda * W \quad \ldots..(9) \qquad \text{or} \qquad L = \frac{\lambda * P_0 \left(\lambda/\mu\right)^s \rho}{s! * \lambda\,(1-\rho)^2} + \frac{\lambda}{\mu} \quad \ldots..(10) \qquad \text{or}$$

$$L = \frac{P_0 \left(\lambda/\mu\right)^s \rho}{s!\,(1-\rho)^2} + \frac{\lambda}{\mu} \quad \ldots..(11) \qquad \text{or} \qquad L = L_Q + \frac{\lambda}{\mu} \quad \ldots..(12)$$

Assumptions :

The following assumptions are made for the model:

1- We assume there is enough storage space in stacking area to store all types of containers according to their blocks.
2- We consider that in the ideal condition, there are enough equipment (cranes, trucks, vehicles etc) to perform all tasks, functions and operations at a container terminal. That means there is no delay or waiting in the performance of those tasks or functions in terms of lack in the number of equipment inside a container terminal.
3- We consider that in the ideal stacking process of containers, the service rate of quay cranes (**SRs**) must be equal to the service rate of yard trucks or vehicles (**SRp**), also equal to the service rate of yard cranes (**SRu**). That means, there is no waiting and delay in the sequences of operations inside container terminal. i.e.

$$\sum_{s=1}^{s=k} \mathbf{ns} * \mathbf{SRs} = \sum_{p=1}^{p=e} \mathbf{np} * \mathbf{SRp} = \sum_{u=1}^{u=h} \mathbf{nu} * \mathbf{SRu}$$

Where, **ns** represents the numbers of quay cranes, **np** the numbers of yard trucks or vehicles and **nu** the numbers of yard cranes.

4- To achieve the best container stacking strategy, the containers must be stacked in blocks, as near as possible as to the berthing positions of vessels, to reduce the transportation time of containers from the quay area to the yard area and vice versa.

5- The containers must be arranged with sufficient leeway in staking area, and they must not be squeezed to capacity, otherwise the number of unproductive moves (reshuffles) will increase due to increase in the number of tiers.

6- We assume the layout of berths in a container terminal is Discrete. That means, the quay is divided into a finite set of berths, and each vessel in this layout can occupy a suitable berth within a specific time. After berthing, the containers are stacked and arranged in the container yard separately according to the import, export and empty containers conditions. Service time for the service centers (yard trucks and yard cranes) is constant, i.e. Static. The arrival of vessels is Dynamic and the vessels cannot berth before the expected arrival time. That means fixed arrival times are given for the vessels for berthing times, or all vessels to be scheduled for berthing have not yet arrived but arrival times are know in advance.

scenario	No. of containers x (TEU)	The max. duration of stay for the vessel in the seaport (day)	No. of quay cranes	λ TEU/hr The output of quay cranes as arrivals to the YTs	s No. of servers (yard trucks)	μ TEU/hr for the yard trucks (YTs)	$s*\mu$ TEU/hr	P_0 Prob. of zero TEU in the system	L_Q average no. of TEU in the queue (waiting)	W_Q average time a TEU spends in the queue (waiting) (hr)	W average time a TEU spends in the system (hr)	L average no. of TEU in the system
1	1000	1	2	60	15	6	90	4.45E-05	0.204085	0.003401	0.170068	10.20408
2	1000	1	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
3	2000	1.5	2	60	15	6	90	4.45E-05	0.204085	0.003401	0.170068	10.20408
4	2000	2	2	60	15	6	90	4.45E-05	0.204085	0.003401	0.170068	10.20408
5	2000	1	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
6	2000	1.5	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
7	3000	2	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
8	3000	2.5	2	60	15	6	90	4.45E-05	0.204085	0.003401	0.170068	10.20408
9	3000	3	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
10	3000	1.5	4	120	25	6	150	1.93E-09	0.836411	0.00697	0.173637	20.83641
11	4000	3	2	60	15	6	90	4.45E-05	0.204085	0.003401	0.170068	10.20408
12	4000	2.5	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
13	4000	1.5	4	120	25	6	150	1.93E-09	0.836411	0.00697	0.173637	20.83641
14	4000	4	2	60	15	6	90	4.45E-05	0.204085	0.003401	0.170068	10.20408
15	4000	2	3	90	20	6	120	2.93E-07	0.481288	0.005348	0.172014	15.48129
16	4000	2	3	90	22	6	132	3.03E-07	0.135656	0.001507	0.168174	15.13566
17	4000	2	3	90	24	6	144	3.05E-07	0.036789	0.000409	0.167075	15.03679
18	4000	2	3	90	26	6	156	3.06E-07	0.009254	0.000103	0.166769	15.00925
19	4000	2	3	90	28	6	168	3.06E-07	0.002125	2.36E-05	0.166690	15.00212
20	4000	2	3	90	30	6	180	3.06E-07	0.000442	4.91E-06	0.166672	15.00044

Table no. (1) : Represent performance measures of the multi-server queuing system at a container terminal (the first stage).

scenario	λ TEU/hr	μ TEU/hr	No. of servers (yard trucks)	$1/\lambda$	$1/\mu$	ρ the average utilization of the system $(\lambda/s*\mu)$	Total service rate (μ * no. of trucks) per hr	$X*W_Q$ Total waiting time in the queue for containers (hr)	$X*W$ Total time for containers in the queue and being serviced in the system (hr)	The max. duration of stay for the vessel in the seaport (day)	$\frac{X*W}{s}$ (hr)
1	60	6	15	0.016666667	0.166667	0.666666667	90	3.401	170.068	1	11.33786667
2	90	6	20	0.011111111	0.166667	0.75	120	5.348	172.014	1	8.6007
3	60	6	15	0.016666667	0.166667	0.666666667	90	6.802	340.136	1.5	22.67573333
4	60	6	15	0.016666667	0.166667	0.666666667	90	6.802	340.136	2	22.67573333
5	90	6	20	0.011111111	0.166667	0.75	120	10.696	344.028	1	17.2014
6	90	6	20	0.011111111	0.166667	0.75	120	10.696	344.028	1.5	17.2014
7	90	6	20	0.011111111	0.166667	0.75	120	16.044	516.042	2	25.8021
8	60	6	15	0.016666667	0.166667	0.666666667	90	10.203	510.204	2.5	34.0136
9	90	6	20	0.011111111	0.166667	0.75	120	16.044	516.042	3	25.8021
10	120	6	25	0.008333333	0.166667	0.8	150	20.91	520.911	1.5	20.83644
11	60	6	15	0.016666667	0.166667	0.666666667	90	13.604	680.272	3	45.35146667
12	90	6	20	0.011111111	0.166667	0.75	120	21.392	688.056	2.5	34.4028
13	120	6	25	0.008333333	0.166667	0.8	150	27.88	694.548	1.5	27.78192
14	60	6	15	0.016666667	0.166667	0.666666667	90	13.604	680.272	4	45.35146667
15	90	6	20	0.011111111	0.166667	0.75	120	21.392	688.056	2	34.4028
16	90	6	22	0.011111111	0.166667	0.681818182	132	6.028	672.696	2	30.57709091
17	90	6	24	0.011111111	0.166667	0.625	144	1.636	668.3	2	27.84583333
18	90	6	26	0.011111111	0.166667	0.576923077	156	0.412	667.076	2	25.65676923
19	90	6	28	0.011111111	0.166667	0.535714286	168	0.0944	666.76	2	23.81285714
20	90	6	30	0.011111111	0.166667	0.5	180	0.01964	666.688	2	22.22293333

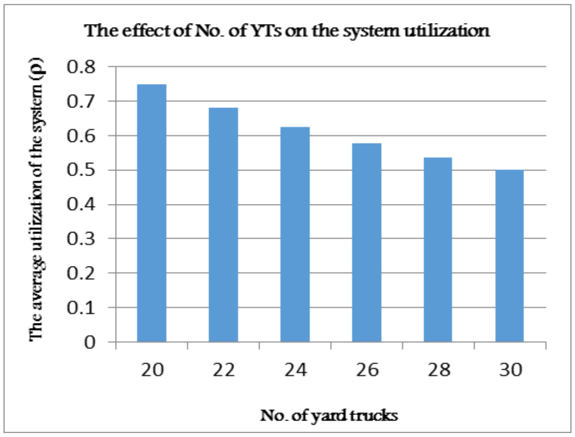
Table no. (2) : Represent the analysis of the multi-server queuing system at a container terminal (the first stage).

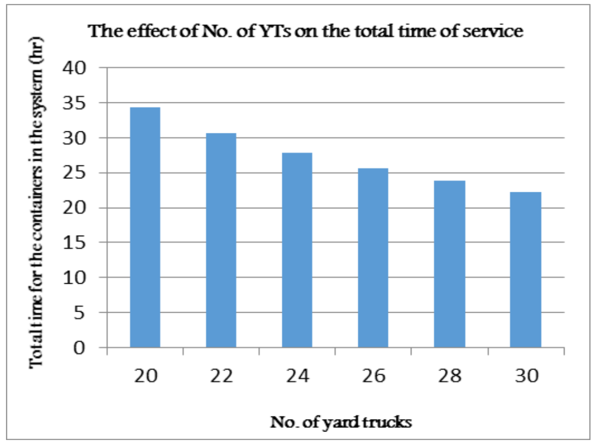
4. Experimental Results and Discussion

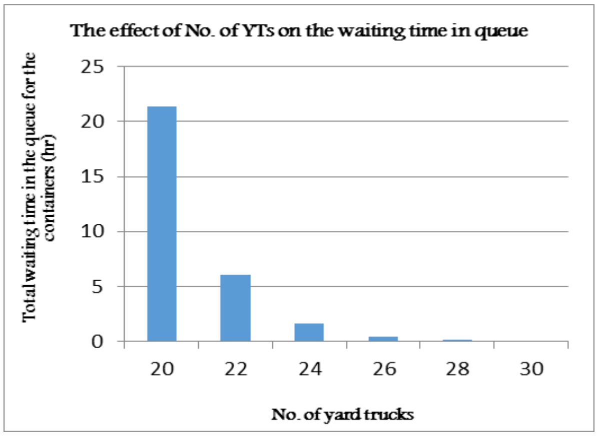
Twenty different scenarios for container stacking inside container terminal are applied to find the optimal service level. These scenarios are varying from each other in terms of quantities of containers, durations of stay for the vessels in the seaport and no. of equipment (quay cranes, yard trucks and yard cranes) that are used to perform the operations.

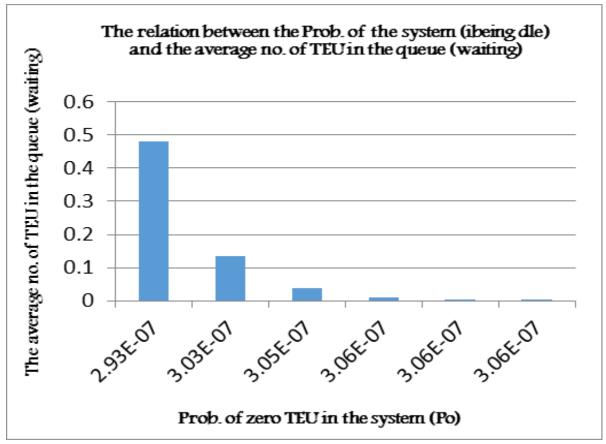
Tables no. (1) and no. (2) show the performance measures and analysis of the multi-server queuing system at a container terminal for the first stage in our case study. Generally, the experimental results show that the increment in the number of service centers (yard trucks) leads to reduce the total waiting time of containers in the queue, the total time for containers that are serviced in the system and the average utilization of the system. That means, we can reduce the waiting cost of containers in the system when we increase the service level (service capacity level), but this procedure increases the service cost or incurs additional expenses, especially if we need to improve the productivity of container terminal.

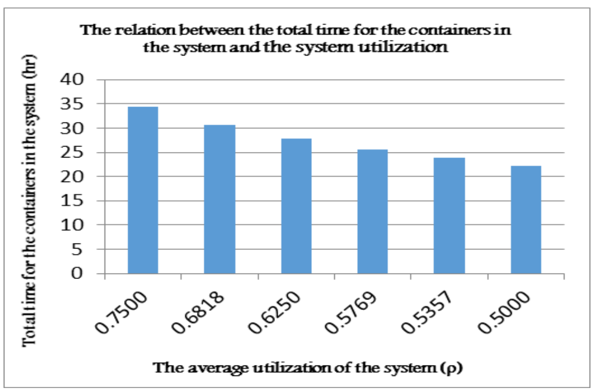
Similar to the analyses in the first stage, tables no. (3) and no. (4) show the performance measures and analysis of the multi-server queuing system at a container terminal for the second stage in our case study, we see also, the experimental results show that the increment in the number of service centers (yard cranes) leads to reduce the total waiting time of containers in the queue, the total time for containers that are serviced in the system and the average utilization of the system.











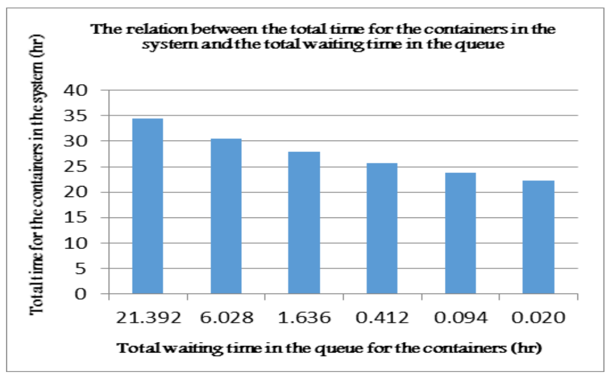


Fig no. (3) Represents the relations between all outputs that are obtained by using queuing theory for the first stage of the container stacking process.

Table no. (5) shows the total time (waiting and service) in the system "container terminal" for both the first and the second stages. In scenarios no. (1) and no. (2), the total times (waiting and service) for both the first and the second stages (14.73887 hr and 17.0848 hr for 1st and 2nd stages respectively in scenario no (1), and 13.9487 hr and 12.10743 hr for 1st and 2nd stages respectively in scenario no (2)) are within the allowance time for the vessel to stay in the berth at a container terminal (one day). That means, if the second stage in both scenarios start after 15 minutes after the first stage, the full process of containers handling, transportation and stacking will finish within the allowance time of the vessel to stay at container terminal.

There is a critical situation in scenario no. (3), the total times for both the first and the second stages (29.47773 hr and 34.1696 hr) are approximately reached to the allowance time for the vessel to stay in the berth (1.5 day or 36 hr). That means, the full process in save but in critical situation.
The total times for both the first and the second stages in scenario no. (4) are the same times in scenario no. (3), but the full process in save, because the duration of stay for the vessel in the berth (2 days) is more than the total times for containers waiting and service at a container terminal.

scenario	No. of containers x (TEU)	The max. duration of stay for the vessel in the seaport (day)	λ TEU/hr The output of quay cranes as arrivals to the YTs and same arrivals to YCs	s No. of servers (yard cranes) YCs	μ TEU/hr for the yard cranes (YCs)	$s*\mu$ TEU/hr	P_0 Prob. of zero TEU in the system	L_Q average no. of TEU in the queue (waiting)	W_Q average time a TEU spends in the queue (waiting) (hr)	W average time a TEU spends in the system (hr)	L average no. of TEU in the system
1	1000	1	60	5	20	100	0.046647	0.354227	0.005904	0.055904	3.354227
2	1000	1	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
3	2000	1.5	60	5	20	100	0.046647	0.354227	0.005904	0.055904	3.354227
4	2000	2	60	5	20	100	0.046647	0.354227	0.005904	0.055904	3.354227
5	2000	1	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
6	2000	1.5	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
7	3000	2	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
8	3000	2.5	60	5	20	100	0.046647	0.354227	0.005904	0.055904	3.354227
9	3000	3	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
10	3000	1.5	120	9	20	180	0.002352	0.391962	0.003266	0.053266	6.391962
11	4000	3	60	5	20	100	0.046647	0.354227	0.005904	0.055904	3.354227
12	4000	2.5	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
13	4000	1.5	120	9	20	180	0.002352	0.391962	0.003266	0.053266	6.391962
14	4000	4	60	5	20	100	0.046647	0.354227	0.005904	0.055904	3.354227
15	4000	2	90	7	20	140	0.010464	0.390998	0.004344	0.054344	4.890998
16	4000	2	90	8	20	160	0.010899	0.133572	0.001484	0.051484	4.633572
17	4000	2	90	9	20	180	0.011042	0.04605	0.000512	0.050512	4.54605
18	4000	2	90	10	20	200	0.011088	0.015478	0.000172	0.050172	4.515478
19	4000	2	90	11	20	220	0.011103	0.004993	5.55E-05	0.050055	4.504993
20	4000	2	90	12	20	240	0.011107	0.001535	1.71E-05	0.050017	4.501535

Table no. (3) : Represent performance measures of the multi-server queuing system at a container terminal (the second stage).

In scenario no. (5), we find the total times for both stages (27.8974 hr for 1st and 24.21486 hr for 2nd) are more than the duration of stay for the vessel in the berth (one day). Therefore, to solve this problem we must increase the number of quay cranes (in the same time, we increase the number of yard trucks in the first stage and increase the number of yard cranes in the second stage) or increase the allowance time of the vessel to stay at container terminal.
We find the scenarios no. (6), (7), (8), and (9) provide the total times for both stages (1st and 2nd) within the allowance time of the vessel to stay in the berth to complete the service. In scenario no. (10), the total time in the first stage (41.74644 hr) is more than the duration of stay for the vessel in the berth (1.5 day or 36 hr). Therefore, to solve this problem we must increase the number of quay cranes (in the same time, we increase the number of yard trucks in the first stage, but the service rate of yard trucks must not exceed the service rate of yard cranes in the second stage), or increase the allowance time of the vessel to stay at container terminal.

The full process of containers handling, transportation and stacking in scenario no. (11) is in save but in critical situation, and the reason for this problem the same that in in scenario no. (3). In scenario no. (12), we see the situation approximately in save. The total times for both stages in scenario no. (13) are more than the duration of stay for the vessel in the berth, especially in the first stage (55.66192 hr), the difference extremely large comparing with the allowance time (1.5 day or 36 hr). Therefore, we need to increase allowance time up to 2.5 or 3 days.
In scenario no. (14), the total times for both stages are less than the allowance time of the vessel to stay in the berth to complete the service.
The scenarios from no. (15) to no. (20) give appropriate indications of container terminal behavior under changing the available resources (equipment, yard trucks, yard cranes … etc) that are used inside a seaport to determine the optimal condition of sequence of operations and the relation between activities and functions of quay and container yard areas. We see when the number of service centers (yard trucks in the first stage and yard cranes in the second stage) increase, all the times (waiting and service), the average utilization of the system, the no. of containers in queue and service will decrease. The figures no. (3) and no. (4) represent the relations between all outputs that are obtained by using queuing theory for both the first and second stages of the container stacking process.
The experimental result show that the scenario no. (20) provides the optimal service time and minimum waiting time for containers to perform all operations that are associated with the container stacking process.

scenario	λ TEU/hr	μ TEU/hr	No. of servers (yard cranes)	$1/\lambda$	$1/\mu$	ρ the average utilization of the system ($\lambda/s*\mu$)	Total service rate (μ * no. of yard trucks) per hr	$X * W_Q$ Total waiting time in the queue for containers (hr)	$X * W$ Total time for containers in the queue and being serviced in the system (hr)	The max. duration of stay for the vessel in the seaport (day)	$\frac{X * W}{s}$ (hr)
1	60	20	5	0.016666667	0.05	0.6	100	5.904	55.904	1	11.1808
2	90	20	7	0.011111111	0.05	0.642857143	140	4.344	54.344	1	7.763428571
3	60	20	5	0.016666667	0.05	0.6	100	11.808	111.808	1.5	22.3616
4	60	20	5	0.016666667	0.05	0.6	100	11.808	111.808	2	22.3616
5	90	20	7	0.011111111	0.05	0.642857143	140	8.688	108.688	1	15.52685714
6	90	20	7	0.011111111	0.05	0.642857143	140	8.688	108.688	1.5	15.52685714
7	90	20	7	0.011111111	0.05	0.642857143	140	13.032	163.032	2	23.29028571
8	60	20	5	0.016666667	0.05	0.6	100	17.712	167.712	2.5	33.5424
9	90	20	7	0.011111111	0.05	0.642857143	140	13.032	163.032	3	23.29028571
10	120	20	9	0.008333333	0.05	0.666666667	180	9.798	159.798	1.5	17.75533333
11	60	20	5	0.016666667	0.05	0.6	100	23.616	223.616	3	44.7232
12	90	20	7	0.011111111	0.05	0.642857143	140	17.376	217.376	2.5	31.05371429
13	120	20	9	0.008333333	0.05	0.666666667	180	13.064	213.064	1.5	23.67377778
14	60	20	5	0.016666667	0.05	0.6	100	23.616	223.616	4	44.7232
15	90	20	7	0.011111111	0.05	0.642857143	140	17.376	217.376	2	31.05371429
16	90	20	8	0.011111111	0.05	0.5625	160	5.936	205.936	2	25.742
17	90	20	9	0.011111111	0.05	0.5	180	2.048	202.048	2	22.44977778
18	90	20	10	0.011111111	0.05	0.45	200	0.688	200.688	2	20.0688
19	90	20	11	0.011111111	0.05	0.409090909	220	0.222	200.22	2	18.20181818
20	90	20	12	0.011111111	0.05	0.375	240	0.0684	200.068	2	16.67233333

Table no. (4) : Represent the analysis of the multi-server queuing system at a container terminal (the second stage).

scenario	No. of containers x (TEU)	The max. duration of stay for the vessel in the seaport (day)	The first stage			The second stage		
			$X * W_Q$ Total waiting time in the queue for containers (hr)	$\frac{X * W}{s}$ (hr)	Total time in the system for the first stage (hr)	$X * W_Q$ Total waiting time in the queue for containers (hr)	$\frac{X * W}{s}$ (hr)	Total time in the system for the second stage (hr)
1	1000	1	3.401	11.33786667	14.73887	5.904	11.1808	17.0848
2	1000	1	5.348	8.6007	13.9487	4.344	7.763428571	12.10743
3	2000	1.5	6.802	22.67573333	29.47773	11.808	22.3616	34.1696
4	2000	2	6.802	22.67573333	29.47773	11.808	22.3616	34.1696
5	2000	1	10.696	17.2014	27.8974	8.688	15.52685714	24.21486
6	2000	1.5	10.696	17.2014	27.8974	8.688	15.52685714	24.21486
7	3000	2	16.044	25.8021	41.8461	13.032	23.29028571	36.32229
8	3000	2.5	10.203	34.0136	44.2166	17.712	33.5424	51.2544
9	3000	3	16.044	25.8021	41.8461	13.032	23.29028571	36.32229
10	3000	1.5	20.91	20.83644	41.74644	9.798	17.75533333	27.55333
11	4000	3	13.604	45.35146667	58.95547	23.616	44.7232	68.3392
12	4000	2.5	21.392	34.4028	55.7948	17.376	31.05371429	48.42971
13	4000	1.5	27.88	27.78192	55.66192	13.064	23.67377778	36.73778
14	4000	4	13.604	45.35146667	58.95547	23.616	44.7232	68.3392
15	4000	2	21.392	34.4028	55.7948	17.376	31.05371429	48.42971
16	4000	2	6.028	30.57709091	36.60509	5.936	25.742	31.678
17	4000	2	1.636	27.84583333	29.48183	2.048	22.44977778	24.49778
18	4000	2	0.412	25.65676923	26.06877	0.688	20.0688	20.7568
19	4000	2	0.0944	23.81285714	23.90726	0.222	18.20181818	18.42382
20	4000	2	0.01964	22.22293333	22.24257	0.0684	16.67233333	16.74073

Table no. (5) : Represent the total time (waiting and service) in the system “container terminal” for both the first and the second stages.

5. Conclusion

This study aims to find the system parameters for the container stacking process in a seaport container terminal under the impact of synchronization and sequence of daily operations and activities between seaside and landside of terminal.

The system is a typical tandem queuing system (the container stacking problem that is associated with functional operations and sub-operations at a typical container terminal is represented as multi-server queues in tandem, consisting of two stages, the first stage being the relation between handling-off process and transportation process, and the second stage being the relation between transportation process and stacking process), and this procedure is useful for the design of container terminals in terms of layout, capacities and control. We compare between the results of many scenarios for the container stacking inside a container terminal to evaluate the performance of the formulated model. According to the outputs, we show how the increment in the number of service centers (yard trucks and yard cranes in the first and second stages) leads to reduction in the total waiting and service times in the system, and the average utilization of the system. Furthermore, we can find the optimal numbers of equipment that should be used in service to achieve the optimal service level.
In future work, we will study the effect of varying arrival rate and the service rate of containers on the service level in a seaport container terminal, and find the optimal resource levels to perform all functions that are associated with

container stacking process. Also, we will focus on the effect of service discipline or the possibilities for containers services under priorities, random order … etc) on the service level inside seaport.

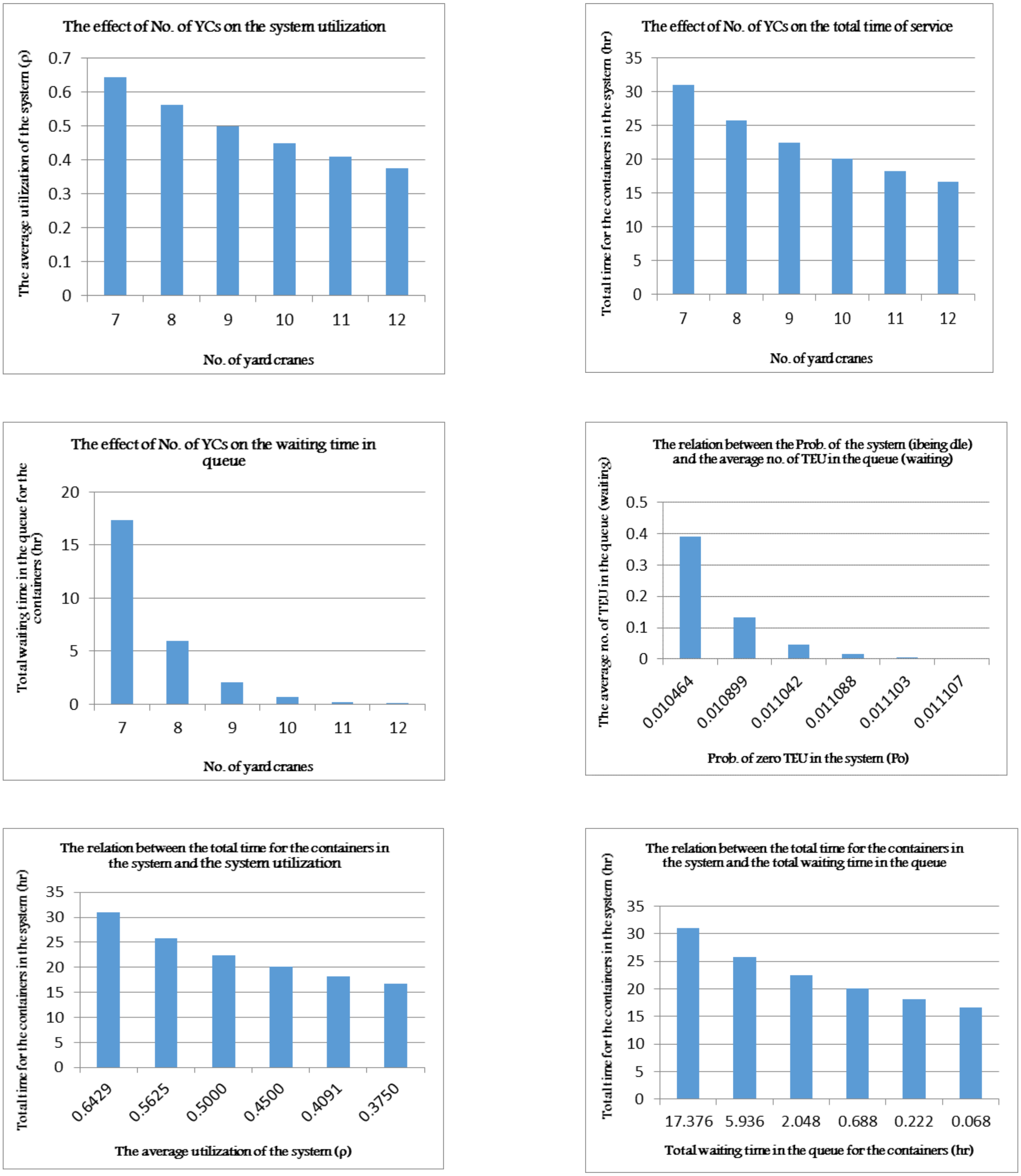


Fig no. (4) represents the relations between all outputs that are obtained by using queuing theory for the second stage of the container stacking process.

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Biographies

VSS Yadavalli is a Professor and Head of Department of Industrial & Systems Engineering, University of Pretoria. Professor Yadavalli has published over 150 research paper mainly in the areas of Reliability and inventory modelling in various international journals like, International Journal of Production Economics, International Journal of Production Research, International Journal of Systems Science, IEEE Transactions on Reliability, Stochastic Analysis & Applications, Applied Mathematics & Computation, Annals of Operations Research, Computers & Industrial Engineering etc. Prof Yadavalli is an NRF (South Africa) rated scientist and attracted several research projects. Prof Yadavalli is serving several editorial boards of various international journals. He supervised several M and D students locally and abroad. Professor Yadavalli was the past President of the Operations Research Society of South Africa. He is a `Fellow' of the South African Statistical Association. He received a `Distinguished Educator Award 'from Industrial Engineering and Operations Management Society in 2015.

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Rafid Al Rikabi is doctorate currently a student of the University of Pretoria. He had his Bachelors and Masters degrees in Engineering from Iraq and currently works as a Diplomat in the embassy of Iraq in Ottawa. His interest is in the area of Operations Management and Supply Chain Management, with particular interest in the management of Sea Ports and planning and optimizing Ports Operations.

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