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Research Article

Research on the effect of number of yard trucks on container terminal throughput

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Abstract
Container terminal productivity is a benchmark for the level of effectiveness of a container port. One indicator of container terminal productivity level can be calculated through yard throughput. Several factors affect yard throughput, one of which is the number of truck terminals. This study aims to investigate the effect of the number of truck terminals on yard throughput at a container terminal. The investigation was conducted using a container terminal simulation which was based on the discrete event simulation method. As a case study, a simulation of a container terminal with a dock length of 300 m with several quay cranes was two units. The simulation was done by parameters adding the number of truck terminals and variations in the capacity of ships coming. The results of the simulation show that an increase in the number of truck terminals affects the number of outputs, depending on the size of the loading and unloading vessels. From the simulation results obtained, the largest yard throughput capacity of 809 containers with the number of truck terminals is 8 units on a shipload of 1,000 twenty-foot equivalent units. The results of this study provide an overview of the needs of the truck terminal in the container terminal.

1. Introduction

Every year the volume of world trade in containers continues to expand. According to statistical data, the total number of containers worldwide exceeds four million twenty-foot equivalent units (TEUs), 266 metric tons of freight equivalent (Statista Research Department; 2020). This certainly affects a container terminal's operational capacity, by extending the port area and increasing the amount of container handling equipment (Veenstra et al., 2012). A container terminal is an area where goods are transferred between land and sea (Vis & Koster, 2003). Here, there is a dynamic mechanism, involving several stakeholders in terms of infrastructure and legislation, as well as risk authority (Budiyanto & Fernanda, 2020). A container terminal has, at least, a berth area, a stacking yard, and an entrance and exit gate, which is more focused on technical factors (Günther & Kim, 2006).

Depending on the type of port configuration, there are many container haulers that operate, including quay cranes, transfer trucks, gantry cranes, and side loaders (Li & Vairaktarakis, 2004). All are arranged in such a way that the operation of container movement is smooth; in the current era, a container terminal is required to have high productivity (Carlo et al., 2014), to be energy efficient (Huzaifi et al., 2020), and to be environmentally friendly (Rijsenbrij & Wieschemann,

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2011; Budiyanto et al., 2019). Actually, several new terminals in developing countries have used automated guided vehicles to manage container transport within terminals to improve productivity (Bae et al., 2011; Liu et al., 2002); moreover, several experiments have been performed to minimize energy usage in container terminals (Budiyanto et al., 2019; Budiyanto et al., 2019), one of which is in refrigerated containers (Budiyanto & Shinoda, 2020; Budiyanto & Shinoda, 2017). The use of technology which leads to automation and minimizes ports pollution is applicable in developed countries, but this is not applicable in developing countries. Developing country ports continue to address the problem of enhancing container port and productivity (Wilmsmeier et al., 2013). Port performance is measured from various viewpoints, such as productivity, relative and technological efficiency, and cost efficiency toward optimal throughput (Zangwa, 2018).

There have been many studies on how to increase throughput. The choice of terminal operating system increases terminal efficiency, and terminals can increase productivity by increasing efficiency and storage, including yard cranes such as train transtainers, tire transtainers, straddle carriers, reach stackers, and tractors (Yang & Lin, 2013). Some researchers have focused on operational level issues, specifically for container loading or ship operations, such as trucking and determining the storage location for containers. Studies have been conducted on the problem of assigning each disposal container to a yard and assigning a delivery vehicle to the container so as to minimize the time to dispose of all containers from a ship (Bish et al., 2001).

Development of a dynamic programming method to determine the storage location of export containers to minimize the number of relocation movements expected for loading operations has been done (Park & Kim, 2003). The distribution and scheduling of container handling equipment in a container yard has been investigated by a number of researchers. A study has been conducted on the problem of spreading yard cranes with the aim of finding the time and route of yard cranes moving between yard blocks to minimize the total delayed workload on container yards (Zhang et al., 2002). A mixed integer programming model is proposed to determine the number of yard cranes to be used in each page block in each planning period. A container terminal is a massively complicated system; therefore, various parts interact with one another. Furthermore, port operators desire to be aware of an automated system's long-term performance. The discrete event simulation approach provides evaluation of the performance of the throughput of container terminals, because it is challenging or impracticable to quantitatively articulate an answer to the concerns above.

There have not been many studies that have discuss the needs of truck terminals in container terminal. From the research gap, the aim of this study is to investigate the effect of the number of truck terminals on yard throughput at a container terminal. This study contributes by providing an overview of the needs of the truck terminal in a container terminal.

2. Research methodology

2.1 Yard throughput

Container terminal operations consist of loading and unloading processes, commonly known as import and export. The import is unloading a container from the ship, and the export is loading the container onto the ship. Generally, the container terminal operations as are shown in **Figure 1**. At this stage, the unloading activity begins with the readiness of the solo guide on board and the operator on land with the quayside container crane (QCC) operator. Solo and whiskey guides, along with QCC operators, communicate effectively and interactively with each other. The containers are unloaded directly to the yard truck (HT), and the HT operator carries the container loads to a location called block-slot-row-tier, which has been planned by the system. Containers that are in the HT are unloaded using an rubber-tyred gantry (RTG), which functions to arrange the containers in the stacking yard. The next step is that the stacking yard officer checks the seal and the physical condition of the container and records the identity and position of the container in the stacking yard. The unloading process is completed by data entry onto the system.

The loading operation is preceded by the preparation of tools, data, and cargo documents, solo on board and operator on land, as well as HT operators and also QCC operators. The next stage is the HT operator transporting the containers from the stacking yard to the wharf. From the container yard (CY), the RTG operator lifts the container (lift on) to HT. Furthermore, the cargo is transported by the QCC operator onto the ship according to the existing layout plan. Loading activities are completed by data entry onto the system by field staff.

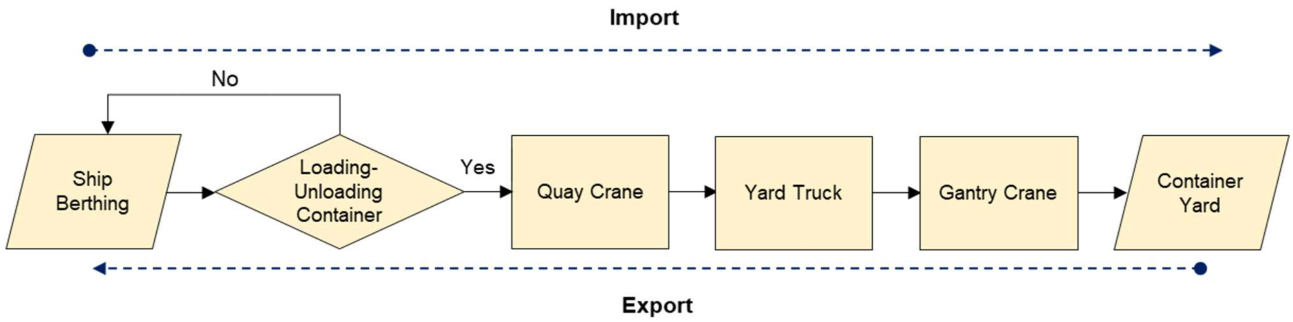

Figure 1 Container terminal simulation process.

Field operations, namely, the activity of moving containers from the stacking yard to the ship's side, or from the ship's side to the stacking yard, are done using a yard truck. Basically, field operation activities are divided into two, namely, horizontal and vertical displacement. Vertical displacement of containers using yard cranes lowers or raises containers (lift on-lift off) from/to trailers. The trailer itself has two types, namely, (a) a single stack trailer of this type is used to transport one container, and (b) a double stack trailer is used to load two containers. In the activity (lift on-lift off), there are two parts to the activity, namely, (a) ((lift on-lift off) unloading activity, the stage where the container landing on the HT from the ship is sent to stacking yards and unloaded using tools such as RTG, Top Loader, or Reach Stacker containers arranged in the field, and (b) (lift on-lift off) loading, the activity of moving containers from the stacking yard by lifting the containers onto a trailer chassis using a tool such as an RTG, Top Loader, or Reach Stacker and then delivering them to the wharf.

Yard Throughput Container Terminal Simulation is a simulation model built on the basis of a simulation of a discrete event. Discrete-event simulation models a system's operation as a sequence of occurrences (discrete) in time (Fishman, 2001). Each event occurs at a certain point in time and marks a change in system status. No improvements to the system are assumed to occur between successive events; hence, the simulation time will leap immediately to the next event date, which is called next event time creation.

Commercial software is used in this study for academic purposes, named FlexTerm. FlexTerm is software specialized in the simulation of container ports (Moffatt & Nichol, 2020). The modules cover all types of port resources, such as the most common port operation of containers, loading operating equipment, horizontal transport equipment, and storage yards. Using this simulation software's 3D graphical display feature, users can configure the simulation model for the dynamic port container and simulate a basic port loading process. 3D FlexTerm structures include crane docks, yard cranes, idle container forklifts, trucks, container boats, shipping yards, roads, port gates, etc.

The purpose of using FlexTerm software is for the user to optimize operating procedures and achieve pre-operation implementing effects through simulation. The effects that the container port simulation model can achieve are: increasing port handling capacity; increasing port equipment utilization and manufacturing efficiency; decreasing ship waiting time; developing a strategy for stacking container storage yards; effectively allocating resources, etc.

2.2 Simulation settings

The operational and organizational connections in a terminal container are very complicated; as a preliminary study, these issues need to be simplified through theoretical problems in the simulation models. The model is based on the following assumptions in this paper:

- Only one container can be filled at a time by trucks.
- The vehicle shall be self-contained and shall not be disturbed.
- Not all equipment shall be considered for failure and maintenance, and all equipment shall continue to work.
- Container grouping is not regarded as being equivalent with all containers.

As a case study, with two quay cranes, the berth data is 300 m long, and daily ship schedules are used as simulation items for the imported and exported containers concurrently. The inventory movements on both ships, from the ship's arrival to the departure, continue to be simulated. There are 600 TEUs for unloading imported boxes and a loading of 600 TEU export boxes. The container size used is the container type only. **Table 1** displays the loading equipment parameters of the container handling equipment.

The quay crane service process includes loading, unloading, and dock crane movement. The method of moving the truck involves the truck being loaded, packed, queue, and being held. The process of operating the yard crane includes loading, unloading, and movement. The model's original state is that the truck waits for orders in the waiting area and waits for exported containers to be placed in all parts of the exported yard at the dock apron. Imported containers from ships are transferred by yard truck to the imported container yard during the service process. All containers exported for shipping are transported to the ships by trucks coming from the imported container yard.

Table 1 Parameter of container handling equipment.

Equipment	Parameter	Value
Ship	Lenght overall	305 m
	Beam	30 m
	Draft	15 m
	Capacity	200 - 1,000 TEUs
Quay crane	Number of unit	2 unit
	Hoist lift heigh	30 m
	Gantry speeds	2 m/s (maximum)
	Moving	40 moves/hours
Yard truck	Number of Unit	Varies 2, 4, 6, 8 units
	Speed	5, 10, 20 m/s
Gantry crane	Number of gantry	1 unit
	Gantry speed	3 m/s
	Trolley speed	4 m/s
	Hoist lift	3 m/s
	Hoist drop	3 m/s

2.3 Container simulation process

When the simulation begins, the truck continues to work during the port loading process simulation. The truck goes to the dock crane while unloading to confirm that the crane at the dock is safe. It carries one container to the yard crane and checks that the yard crane in the slot is open; then, loading and unloading operations are conducted.

When under loading conditions, the truck goes to the yard crane to check if the yard crane is free of charge. It takes a container to the dock pier in the storage yard and tests whether the dock crane is free to accept the shipment of the dock crane. When the dock cranes or yard cranes are busy, the truck waits in line, simulating the period until all imported containers are unloaded and all export containers are ready. **Figure 1** shows the basic simulation application process. There are several object functions used in this study. Chassis pool is the location where empty chassis is picked up or unloaded. Cranes are used to move containers from yard to ship or vice versa. The position of this crane is on the edge of the berth, and can move along the edge, as long as there are no other objects. Dual trolley cranes move containers to and from one ship in sets of two.

The position of this crane is on the edge of the berth and can move along the edge as long as there are no other objects. Gantry cranes are overhead cranes on wheels that are in the yard block and lift containers. These are typically used to move containers from/to trucks, and to/from yard blocks. Gate planners are used to create operating gates on the model. The gate process is the post that trucks pass when entering or leaving the gate, and is used to represent the time delay at the gate. Gate queue is used as a waiting area for trucks, as in the gate process. The gate road is the path for traveling in models. Road is used together with the gateway model, while network node is used together with the page model. The gate sink is where the container exits the gate and leaves the model permanently. It is used to destroy or recycle flow items, such as containers.

The gate to yard and yard to gate are required interfaces for the gate model. These objects are used to specify the travel time for trucks to enter or leave the yard. These objects can also be used to abstract pages in the gate model only. Network node is used to control the travel path and direction of the operator. Rail block is the equivalent of a single rail line. Multiple rail blocks can be combined in tail planner to form a track area. Rail block is an area for arriving and departing trains. It consists of cells laid out in a row with multiple columns or spaces. The resource group is the command center for a group of gantry cranes or top loaders. When multiple paged resources operate on the same block or area, resource groups are used to assign assignments to resources.

Page resources can still work without resource groups, but using them helps distribute work more evenly and prevents RTGs from crossing over one another, making it more realistic. Straddle carrier transports containers (flow item) in models. This object can move containers to/from ships or yard blocks. The strad gang is a group of straddle carriers who move containers around the model. This object allows to set the number of strads in the aisle, as well as loading and unloading time and strad speed. Top loader is a mobile crane used to move containers in yards. These are typically used for moving and unloading containers from trucks in certain yard blocks. Traffic control is used to control operator travel in the network to prevent congestion and collisions.

Transfer area is a special network node used by trucks and strads to determine where to travel when stacking or detaching the stack from a block. This is often used in automated terminals which have a final loading block. Trucks are used as a means of transporting containers (flow items) in the model. Objects can move containers to/from ships, block yards, or gates. The truck gang is a group of trucks that move containers around the model. This object can be used to set the number of trucks in the aisle, as well as the loading and unloading time and speed of the trucks. The wheeled block is similar to the yard block in that it is a storage area for containers. In this case, the containers are stored side by side on the chassis, and not stacked vertically as in block yard. Wheeled blocks take up more yard space than yard blocks, but are quicker to load and unload and do not require the aid of a crane. Yard block is a storage area for containers. It consists of cells arranged in rows and columns. Yard to gate and gate to yard are the interfaces required when connecting the yard model to the gate model. These objects are used to set the travel time for trucks to enter or leave the yard.

3. Results and discussion

3.1 Increasing the number of quay cranes

From the terminal container simulation, several results were obtained that could contribute to the study of the effect of increasing the number of yard trucks on yard throughput. The results obtained in this study are for the effect of increasing the number of truck terminals on the yard throughput with container capacity variations from 200 - 1,000 TEUs. The first result we get is the size of the yard throughput with the number of truck terminals being two, shown in **Figure 2**. The results show that the more trucks used, the greater the yard throughput generated. By using two yard trucks, the biggest yard throughput is obtained, namely, 798 containers with a capacity of 1,000 TEUs.

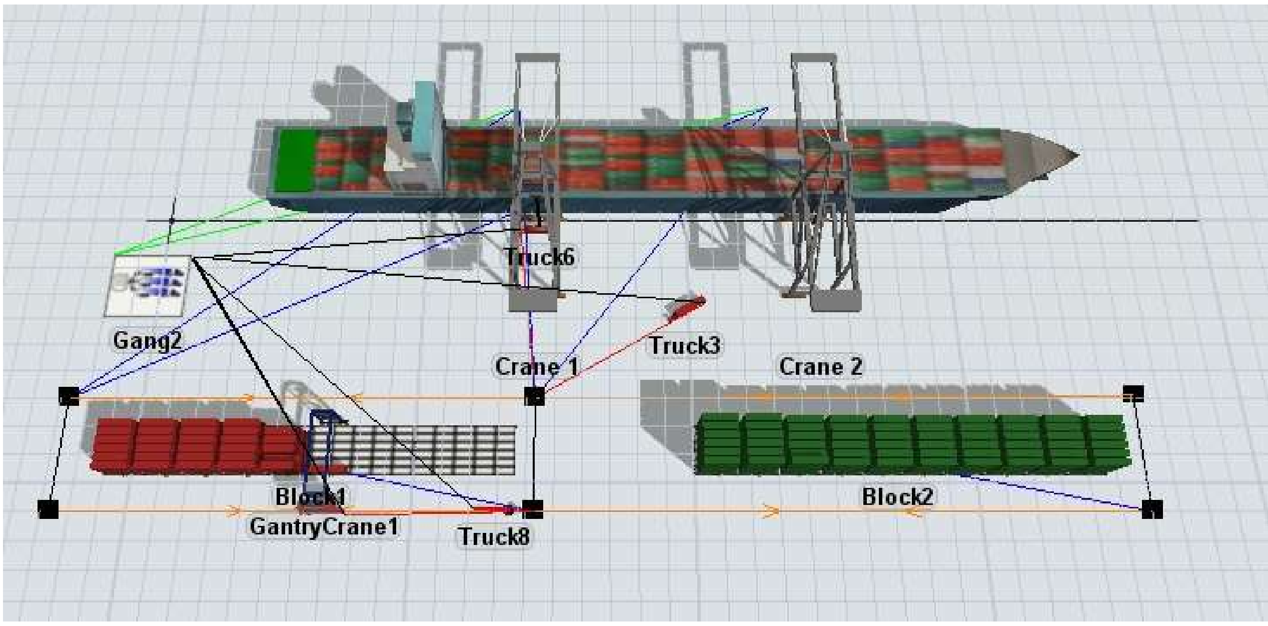

Figure 2 Container terminal simulation process.

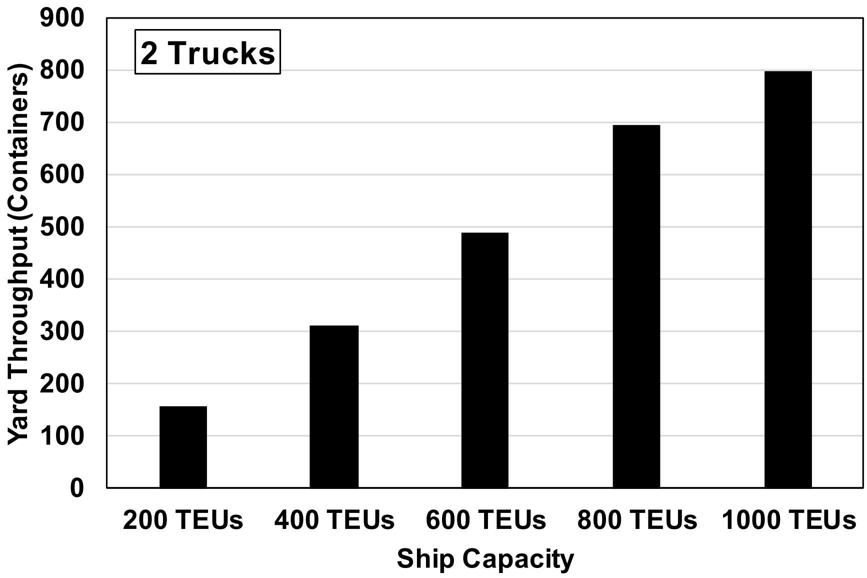

Figure 3 Number of yard throughput with two yard trucks.

Figure 3 displays the results of yard throughput simulation using four yard trucks. The results show that the more trucks used, the greater the yard throughput produced. By using four yard trucks, the biggest throughput yard is 776 containers with 1,000 TEU capacity vessels. **Figure 4** displays the results of yard throughput simulation using six yard trucks. The results show that the more trucks used, the greater the yard throughput produced. By using six yard trucks, the biggest throughput yard is 796 containers with 1,000 TEU capacity. **Figure 5** displays the results of yard throughput simulation using eight yard trucks. The results show that the more trucks used, the greater the yard throughput produced. By using eight yard trucks, the biggest throughput yard is 798 containers with 809 TEU capacity.

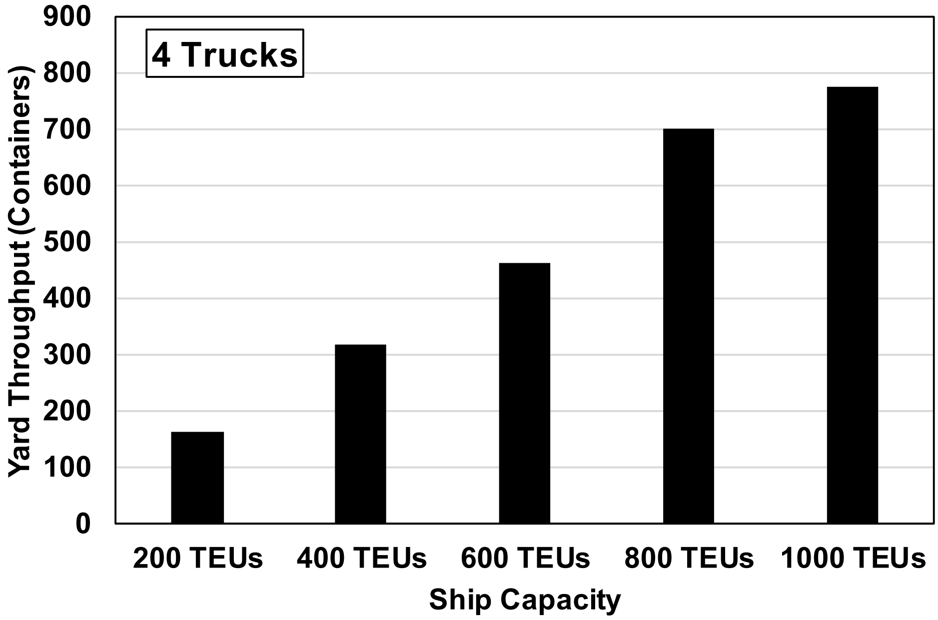

Figure 4 Number of yard throughput with four yard trucks.

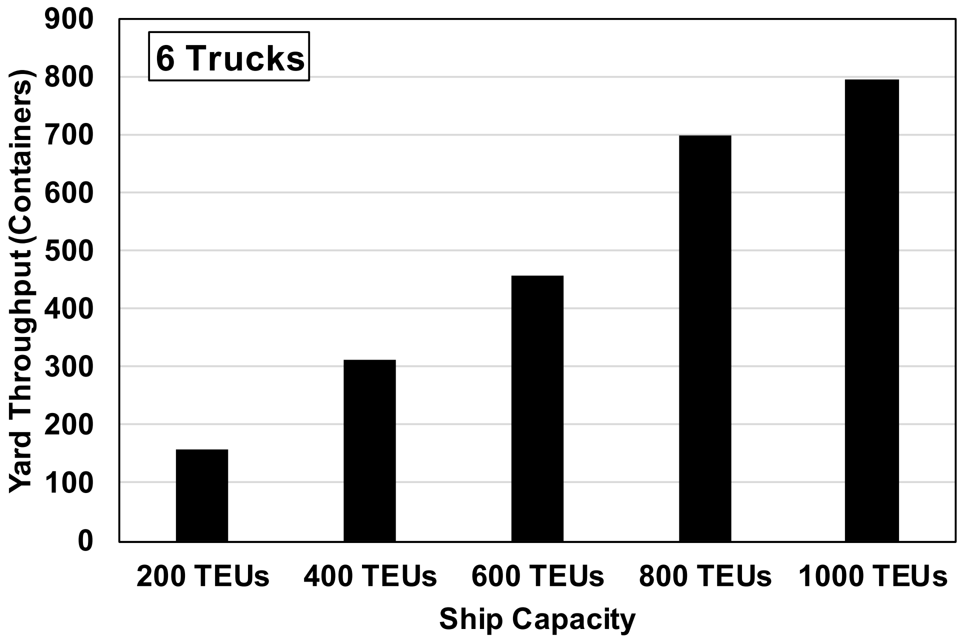

Figure 5 Number of yard throughput with six yard trucks.

Figure 6 shows the effect of increasing the number of truck terminals on overall yard throughput. These results show that the optimal number of truck terminals varies according to the capacity of the ship. From the results of this simulation, the initial results are for the largest 200 TEUs yard throughput capacity using four yard trucks, for the largest 400 TEUs yard throughput capacity using eight yard trucks, for the largest 600 TEUs yard throughput capacity ships using two yard truck, for the largest 800 TEUs yard throughput capacity ships using six yard trucks, and for the largest 1,000 TEUs yard throughput capacity ships using eight yard trucks.

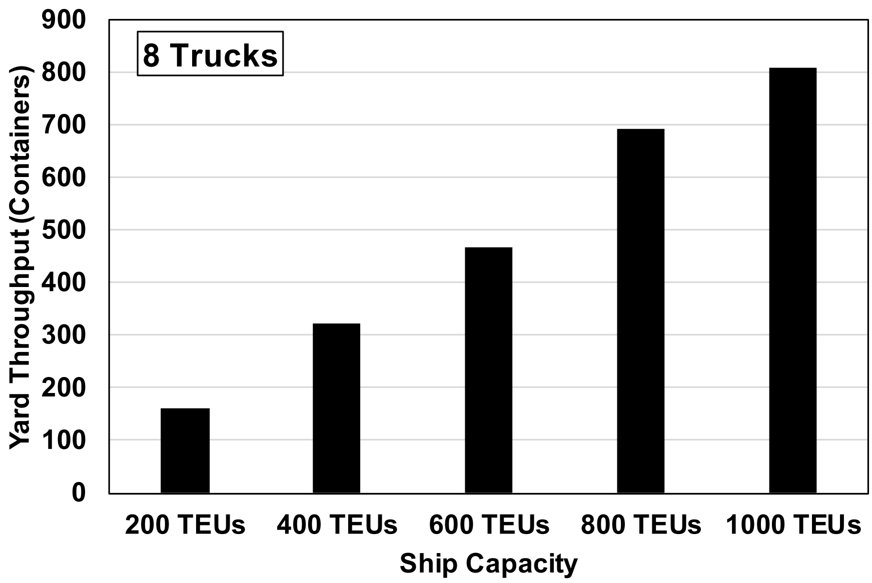

Figure 6 Number of yard throughput with eight yard trucks.

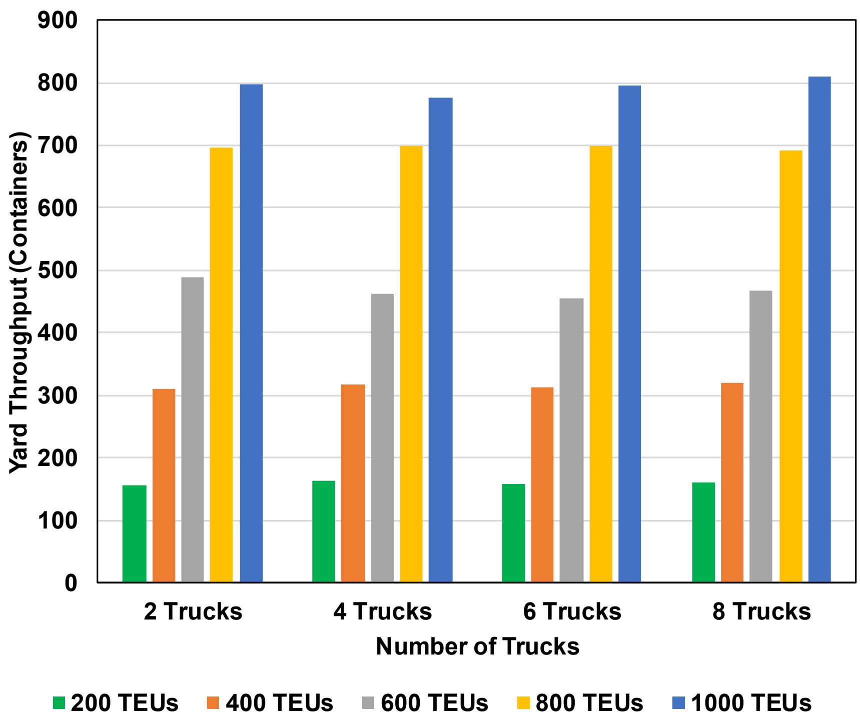

Figure 7 Effect of increase of terminal trucks on number of yard throughput.

3.2 Effect of yard truck speed

In addition to simulating the increase in the number of trucks, this study also tries to see the results of yard throughput by creating a variable increase in the speed of the truck terminals. Simulations are carried out only on ship capacity of 1,000 TEUs; this is because, at this capacity, the number of trucks used is the most with maximum results. **Figure 7** shows the effect of truck terminal speed on the number of yard throughput. From these results, the increase in speed at the truck terminal is not significant to increase yard throughput. This shows that, if the truck terminal speed is increased, then it is possible that the truck is waiting at the quay crane or at the gantry crane. Therefore, to get the optimal truck speed, it is necessary to do integrated scheduling between the truck terminals, quay cranes, and gantry cranes.

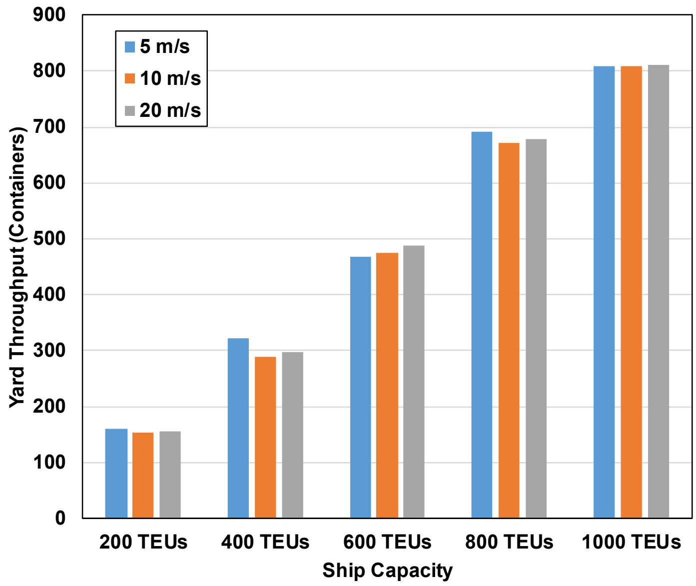

Figure 8 Effect on speed increase of yard trucks.

3.3 Effect of number of trucks on throughput

From the simulation results, the throughput of the container yard is obtained, as shown in **Figure 8**. Yard throughput is the total number of containers that have entered and left the yard. From this simulation, the throughput yard is obtained, which is calculated from the time the ship starts loading and unloading until it finishes leaving the port, with the x-axis variations in the number of truck units and the y-axis the number of content or container units. The throughput results from two quay crane units operating are almost close to the throughput results from one quay crane unit operating. However, the time required for loading and unloading operations with two quay crane units is faster than one quay crane unit. This is because, in the operation carried out by two quay crane units, a mixed mode of operation occurs, so that trucks are able to deliver and place containers at the same time. Meanwhile, when a quay crane operates one unit, a truck can only deliver or place one container in one operating cycle. This operation is called operation mode independent, in which this operation must complete the operation sequentially and cannot be done simultaneously with other operations.

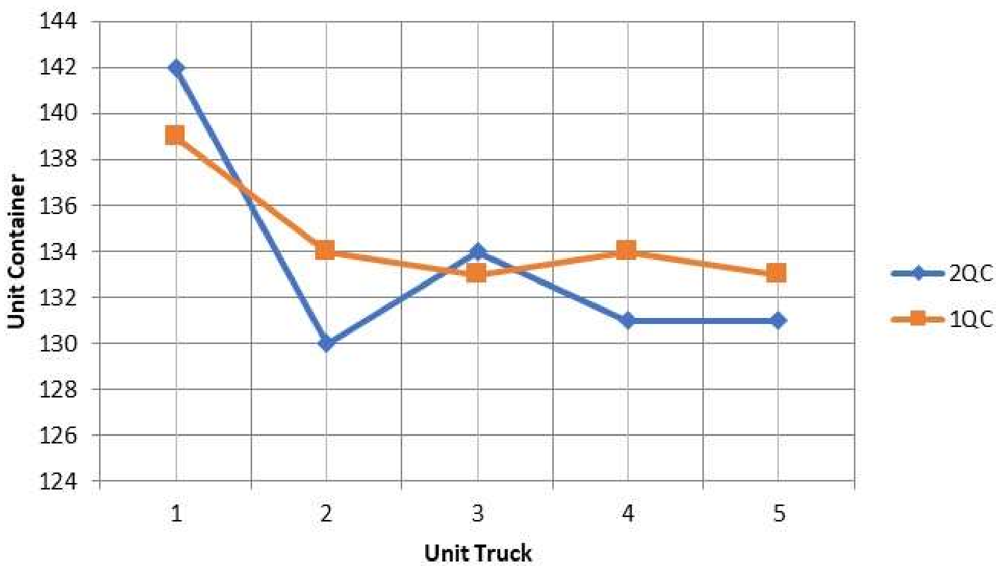

Figure 9 Container yard throughput.

Figure 9 is the utility of container handling with the x-axis, namely, the ratio of quay cranes and trucks, and the y-axis, namely, the percentage of utilities. The simulation results show that the change in the utility level of the trucks for each quantity variation is not large or significant. However, the level of truck utility is greater. Utility is the ratio of the use of operating equipment during the loading and unloading of containers during the time the ship is anchored. In this result, it is known that the quay crane utility reaches 100 %, because the quay crane operates during loading and unloading, or while the ship is anchored, while trucks depend on how many units are used when loading and unloading operations occur, or when the ship is anchored.

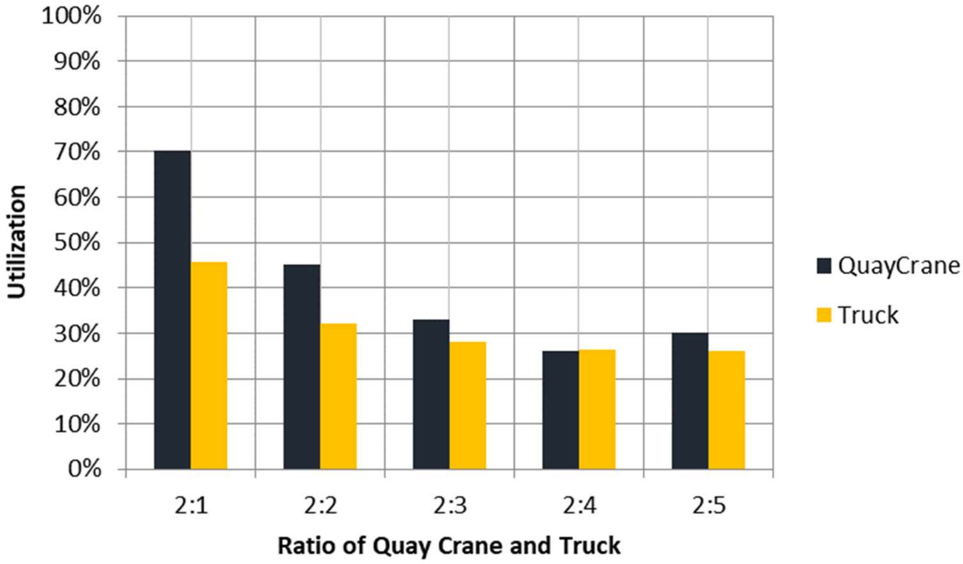

Figure 10 Utilization of quay crane.

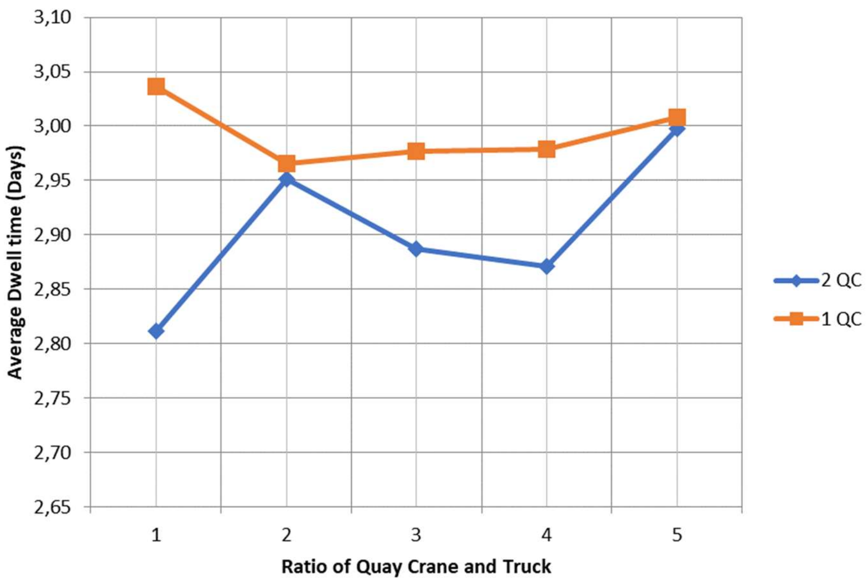

Figure 11 Average dwelling time to ratio of quay crane.

3.4 Effect of number of trucks on dwell time and berth occupancy

Figure 10 shows the average dwell time that occurs in the yard with the x-axis, namely, the variation in the number of trucks, and the y-axis, namely, the average dwell time in days. From the simulation results, it can be seen that the longest average dwell time is around three days and, when compared between the two graphs 1 QC and 2 QC, there is an average dwell time that is almost close, namely, when the ratio of quay cranes and trucks is 1:2 and 2:2 and 1:5 and 2:5. Of the four ratios, the average dwell time is almost close. From the simulation results, it can be seen that the dwell time when the quay crane operates is two units lower than the dwell time when the quay crane operates one unit. This is because the loading and unloading time is faster when the quay crane operates two units, so that the resulting dwell time is lower (**Figure 11**).

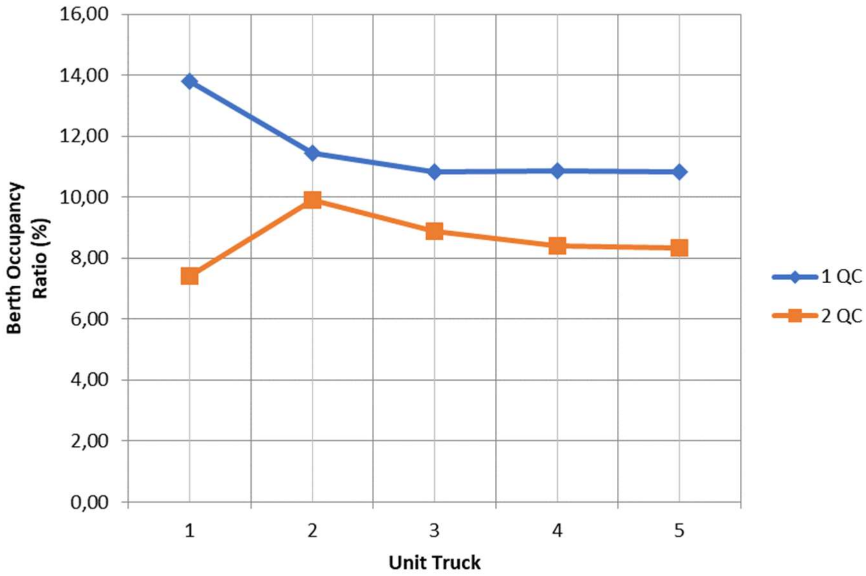

Figure 12 Berth occupancy ratio of container terminals.

Berth occupancy ratio means the length of time a ship occupies a dock within one day. **Figure 12** shows the magnitude of berth occupancy with the x-axis of variations in the number of trucks and the y-axis of the large percentage of berth occupancy. When using one QC, it is found that there is a decrease in berth occupancy, as the number of trucks with one quay crane unit operating increases. When compared, the percentage of berth occupancy when the quay crane is operating is two units lower than when the quay crane is operating one unit. This is because the loading and unloading process occurs faster, so the ship does not need to stay longer at the dock; therefore, the percentage of berth occupancy is lower when the quay crane operates two units. The highest berth occupancy in chart 1 QC is 13.8 %, with a quay crane and truck ratio of 1:1. Meanwhile, the highest berth occupancy is in chart 2 QC, which is 10 %, with a quay crane and truck ratio of 2:2.

4. Conclusions

Research on the effect of increasing the number of truck terminals on yard throughput has been completed using a simulation method. Container terminal simulation based on discrete event simulation has been carried out using FlexTerm commercial software. Simulations have been carried out to find yard throughput with the parameters of the number of truck terminals and container ship capacity. The simulation results show that the yard throughput increases with the addition of the number of truck terminals in line with the increase in ship capacity. From the simulation results, the average yard throughput capacity of 809 containers with a number of truck terminals is 8 units with a shipload of 1,000 TEUs. The results of this study give an overview of the truck terminal's needs within the container terminal. From the results of the analysis, it was found that adding the number of units of resources can increase or decrease the utility of other resources, but that it did not change significantly. This applies to trucks that have been simulated in this research model. Adding quay cranes to two units has an effect on time efficiency in loading and unloading operations. The utility at the container terminal is affected by the amount of resource allocation at the port itself. Comparison of the ratio of resources must be adjusted to the location or geographical location of the port.

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