Stacking Activity Modeling in Tanjung Priok Container Terminal Using Discrete Event Simulation

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Abstract

Tanjung Priok Port and international trade are two things that cannot be separated. However, the performance of the Tanjung Priok Container Terminal is currently not optimal even though Tanjung Priok is the main port lever in Indonesia in terms of exports to foreign countries. As a result, increasing the productivity of container ports in serving container traffic flows is essential. In order to improve container terminal productivity, this study will create a model and simulation of container stacking in the stacking yard (stacking area). A proper stacking procedure (stacking rules) will limit the amount of reshuffling, which is a waste in container operations. The study's findings are discrete event simulation-based models that may be used to evaluate container stacking options based on container terminal productivity. As a result, it is planned to provide an understanding of the relationship between productivity and container stacking procedures in stacking yards.

Keywords
Discrete Event Simulation, stacking rules, stacking yard, reshuffling, port productivity, container terminal, modeling

1. Introduction
AInternational commerce promotes economic freedom, which can be used to boost a country's prosperity. Furthermore, economic freedom might motivate all manufacturers to improve product quality in order to compete in the global market. Foreign commerce plays a direct and indirect role in economic development by increasing foreign exchange revenues, transferring capital and technology from outside, and developing new domestic industries or industrialisation (Muchtar 2001). Because it is a source of foreign exchange for the country's income, the movement of export-import goods between countries promotes economic growth. In 2021, Indonesia's imports will total USD 196,190.0 million (up 38.58 percent), with oil and gas imports being USD 25,529.1 million and non-oil and gas imports totaling USD 170,660.9 million. Tanjung Priok Port is the largest unloading point for imported products, accounting for 38.63 percent of the total (USD 75,786.3 million). Indonesia's export value would reach US$231,609.5 million in 2021, up 41.92 percent from 2020. (BPS 2022). The expansion of supporting infrastructure, such as ports, container terminals, and road infrastructure connecting to ports, must be capable of accommodating the increase in commercial activity. This is because Indonesian ports handle the vast majority of world trade.

Tanjung Priok port is the epicenter of Indonesian export trade. This is corroborated by Export Data by BPS Port of Loading for 2021, which shows that Tanjung Priok handles the majority of Indonesia's exports. Tanjung Priok accounts for 44.39 million tons (27%) of Indonesia's net export weight of 163.12 million tons in 2021. Tanjung Priok has a total export value of USD 55.7 billion (24%) of the total value possessed by the country, which is USD 231.6 billion (BPS 2022). Tanjung Priok, on the other hand, has a less competitive performance when compared to Asian ports. Yangshan, on the other hand, is ranked first in East Asia in terms of overall efficiency, analysis on port efficiency (CPPI indicator), with an index score of 183.5. The CPPI 2021 employs two methodological approaches: an administrative, or technical, approach, a pragmatic methodology based on expert knowledge and judgment, and a statistical approach based on factor analysis. The reasoning behind using two methodologies was to ensure that the ranking of container port performance represents actual port performance as precisely as possible. In the same study, the CPPI rated Indonesia 37th out of 66 analyzed ports in Asia, with a score of 28.2. (World Bank 2021). Tanjung Priok is ranked 124 out of 370 ports in the World Bank database, according to the Container Port Performance Index

(World Bank 2021). It was demoted (-58) from the 2020H1 ranking.

According to Hui (2019), data envelopment analysis (DEA) was used to analyze total port efficiency over infrastructure provision. The port efficiency index appears to have a linear relationship with infrastructure provision. According to the graph, Indonesia has less infrastructure and efficiency than other countries.

According to Hadi, GM PT Pelindo, the realization of dwelling time reached additional 3.11 days in June 2022 due to delays in ship arrivals from other international ports experiencing ship schedule disruptions. As a result, the export container to be loaded accumulates in the CY for an extended period of time (Puspa 2022). Tanjung Priok's stacking time has a direct impact on the Dwelling Time. Dwelling time is estimated from the moment a container is loaded and unloaded from the ship until the time the container leaves the port via the main pier (Anita & Asmadewa 2017). In the moment, the level of dwell time at Indonesian ports is extremely high. In Indonesia, the typical length of stay is 5 to 7 days. This time is very long when compared to Hong Kong's 2 day stay, Singapore's 1.5 day stay, Laem Chabang in Thailand's 5 day stay, Australia's 3 day stay, and Port Klang in Malaysia's 4 day stay (Rafi & Purwanto 2016).

Several factors, including the landfill's capacity, the loading/unloading facilities employed by each terminal operator, the amount of density of container loading and unloading handled, and so on, can have a significant impact on the length of dwell time. The high level of port loading and unloading in Indonesia has an impact on the country's economic sector (Gultom, 2017). Domestic industries geared to exporting to other countries will face productivity challenges. Stowage planning, wharf allocation, crane optimization, transportation optimization, and container stacking are all factors that influence container terminal productivity.

Low reshuffling affects port terminal productivity rise (Stahlbock and Voβ 2008) and makes the port's country position better in the maritime logistics globe. The accumulation of containers in the stacking yard is one of the elements influencing the speed of ship loading and unloading activities.

As a result, this research is valuable in comparing the strategies utilized by container terminals in stacking containers in the stacking yard area. The stacking yard approach has the following goals: efficient use of stacking yards, minimizing time for container movement to and from ships, and minimizing reshuffling. According to the prior explanation, the problem statement for this research is low rate efficiency in container stacking operations (affects reshuffling), which has a negative influence on port terminal productivity. Then, using a discrete event simulation approach, this study intends to test three different container stacking rules in container stacking activities.

1.1 Objectives
Based on the previously described research problem, the goal of this research is to develop a discrete-event simulation-based model of container terminal operations centered on container stacking activities in the stacking area. This research will also aim to learn about the design and operation of container terminals and determine the best stacking rules based on the least reshuffling from simulation.

2. Literature Review
Terminals for containers are ports where containers change modes of transportation (Stahlbock & VoS 2008). This facility connects maritime and terrestrial traffic. The flow of goods commerce by sea employs the mode of maritime transport. The container terminal will facilitate the exchange of containers between the marine route and the land route. Trucks and railroads will be used to transport land-based cargo. The container terminal is separated into four primary sectors, each with its own role (Meisel 2009). The four areas are as follows: Quay Area where the ship rests and the loading and unloading activities of containers from and to the ship; Transport Area, a container transportation area inside the container terminal; Yard Area where containers are piled up before changing to the next mode of transportation; Truck and train area, a place where containers are moved from and to trucks or trains.

The container is a reusable iron box in the shape of a cube that serves as a means of carrying products (Levinson, 2008). Containers provide standardization of goods packaging media and the ability to be carried by a variety of means of transportation, including trucks, trains, and ships (Theo Notteboom 2008). Containerization technology has a significant impact on the transportation of products. This technique improves the efficiency of high- value loads by 85 percent and decreases loading time and expenses by 35 percent. Since 1952, when the first container ships began

operations in the United States and Denmark, numerous container-related designs, volumes, and technologies have emerged (Alderton, 2008).

According to Li, Wu, and Goh (2015), there are three categories of containers at container ports based on their destination: export containers, import containers, and transshipment containers. The container terminal's working area is separated into four sections: the wharf area, the transfer area, the field area, and the hinterland. The transportation of export containers from the hinterland to the container terminal and import containers from the container terminal to the hinterland is the operational procedure in the hinterland. External trains or trucks are used in this transfer, which are trucks owned by parties other than the container port operator (Li, Wu, & Goh 2015). The description of the flow of the operating process at the container terminal is described in Figure 1.
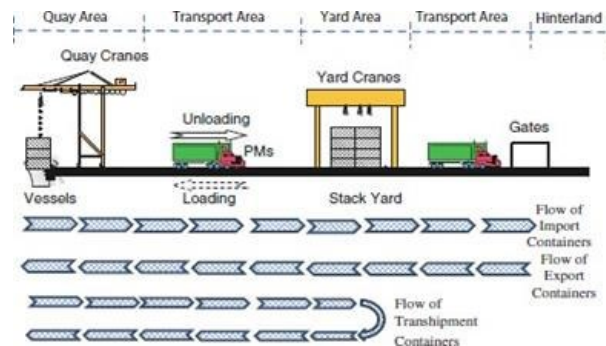

Figure 1. Flow of the operating process at the container
Source: Li, Wu, and Goh (2015)

Container stacking is the act of stacking containers in a yard area. Stacking containers is one of the benefits of containers that tries to maximize land usage efficiency in container storage (Alderton 2011). One of the keys to container terminal productivity is this action in container stacking (Stahlbock & VoS 2008). Container stacking is quite important in terms of container loading time aboard the ship. Good container stacking will reduce the amount of reshuffling during the loading of containers into the ship. The fewer reshuffling that occurs, the faster the loading procedure into the ship. In the end, it will shorten a ship's docking time. The following goals are achieved by stacking containers in an effective and efficient manner: efficiency of the stacking yard area, reduction of transportation time, and avoidance of reshuffles. The usage of land in container storage will be influenced by effective and efficient container stacking. However, large container stacking has an additional effect on the increased chance of reshuffling due to very high container stacks (Borgman, Asperen & Dekker 2011).

Container stacking at the container terminal can be done in a variety of ways and approaches. These approaches are tailored to their unique stacking container goals. Container stacking methods are broadly classified into two types: category stacking and residence time stacking. Category stacking is a way of stacking containers based on their similarities in categories. These categories can be based on weight, destination, or container type (Dekker et al. 2006).

Category Stacking Based on Vessel involves stacking containers in the stacking area based on the qualities of the ship contained within the container. Each container has a characteristic that serves as the container's identity. The name of the ship that will convey the container is one of the identities contained in each container. Each container with the same ship attribute will be sorted in the same pile in the same order as the container with the same ship attribute. If the allocation for containers with the same ship attribute is no longer available, this will not apply. As a result, the container must be positioned in a different pile with the shortest stack height. Category Stacking Based on Destination arranges containers according to their category. The container's purpose is the category employed in this investigation. Each container has a final destination known as the Port of Destination (POD). So, using this strategy, the containers are ordered according to their POD. Containers that have just arrived at the stacking yard will be stacked on top of containers with the same POD. Reshuffling is an action that is considered as container terminal operating waste. One technique to assess the effectiveness of container terminal performance is to examine the reshuffles parameter. The percentage of reshuffles compared to the entire activity of moving containers in the stacking yard area is used to calculate reshuffles. Each rearrangement will have an effect on any subsequent reshuffles. As a result, this measure becomes one of the most essential indications in determining a container terminal's performance efficiency.

3. Methods (12 font)

Mes (2017) claims that simulation may be used to study physical phenomena, business processes, pedestrian and traffic movement, as well as manufacturing and logistical activities. There are primarily two types of simulation: time-oriented simulation (continuous or time-step simulation) and Discrete-event simulation. Time is continuous in the actual world. For example, observing a part go down a conveyor system will reveal no time jumps. Because the time it takes the component to traverse the system is continuous, the curve for the distance traveled is a straight line. A discrete event simulation (DES) software, on the other hand, only considers those moments in time (events) that are important to the simulation's overall outcome. According to Siemens (2019), the process during DES is especially handy when simulating numerous configurations of the same system and doing multiple replications for each configuration. Plant Simulation has built-in functionality for just the purpose of DES claims Siemens. The characteristic of DES is shown in Figure 2.
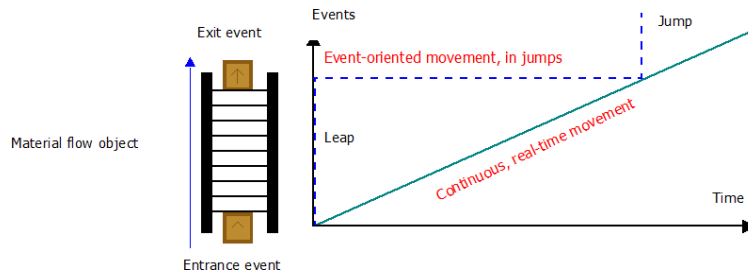

Figure 2. Characteristic of Discrete Event Simulation
Source: Siemens (2019)

The discrete-event simulation is a simulation that is time-based. The variability of a model is directly related to time-based discrete-based models. Variability can occur in an entity's arrival time, processing time, and ability. Variability in a model is beneficial for simulating uncertainty in real-world systems. As a result, variability is a key aspect of discrete-based simulation. Variability is accommodated in a computer system using random numbers (Robinson, 2014).

4. Data Collection

The ship will arrive at the port according to a predetermined schedule. Each ship has a name and capacity attribute. The ship will dock at the port until all containers are filled with capacity. After the ship arrives at the port, the head truck will head to the stacking area to pick up the containers that are arranged in the stacking area. When it will be taken from the stacking area, containers that will be transported by ship must be ensured that they are on the top stack. If these conditions are not met, a reshuffling activity must be carried out to retrieve the container. Then the containers are loaded onto the head truck.
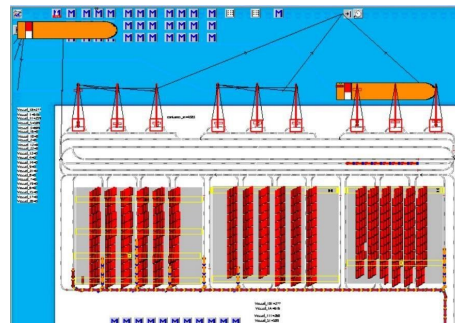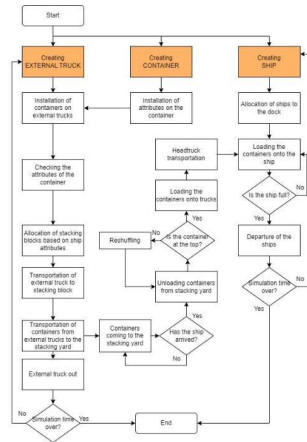

Figure 3. Model in Plant Simulation

Figure 4. Base Flow Chart Model

One of the goals of establishing this model is to help users understand the architecture of operations at container ports. One approach is to create a model that is supported by visualization to help users comprehend the model. As a result, we require objects that may represent the current state of the container terminal. The simulation lasted 9 days. There is an initialization stage of the stacking area before the simulation is conducted to load the stacking area with containers. Because the simulation must be done in a steady-state stage with the stacking space already full of containers. The initiation phase lasted four days and twelve hours. The simulation will execute container actions for 13 days and 12 hours in total. The model visualization and flow are shown in Figure 3 and Figure 4.
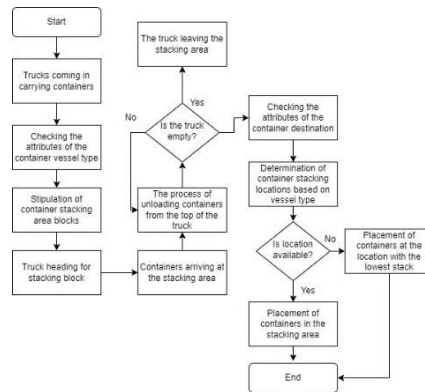

Figure 5. Flow Chart of Category Stacking Based on Vessel

The first method modeled on this container terminal model is category stacking based on vessels. This method has the goal of stacking containers with the same ship attributes on the same pile. So that each container will be stacked in groups according to the ship that each will transport it. The attributes of the ship that will transport are useful when the process of unloading containers from the stacking area is carried out to be transported onto the ship. So that the container to be unloaded is not obstructed by piles of containers with different ships. The flow chart is shown in Figure 5.
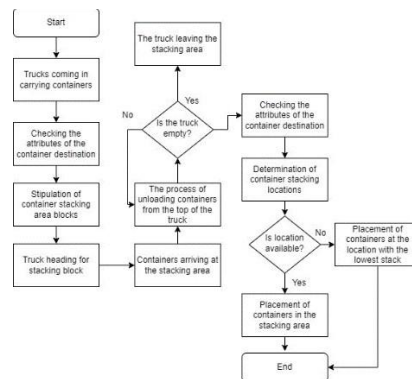
Figure 6. Flow Chart of Category Stacking Based on Destination

The next method used as a comparison in stacking containers in the stacking area is category stacking based on destination. This method is a method of stacking containers based on the categories in the containers. The category used as a reference is the purpose of each of these containers. Purpose is useful to serve as a reference because it is one of the considerations when carrying out stowage or stacking on board. The container with the farthest destination must enter the ship first because it will be at the bottom of the stack. The process of stacking containers using the category stacking method based on destination can be seen in the following flowchart in Figure 6.

5. Results and Discussion
Following the collection and processing of data in the previous chapter, the next stage is to assess the findings of the investigation. In the container stacking area, this chapter will compare the 3 approaches for stacking containers. The ultimate result is a description of container stacking processes in the stacking yard area. The end result of this chapter will provide a foundation for the following chapter, namely the chapter of findings and recommendations.

The analysis and outcomes of this study will be presented after an explanation of the factors employed as indicators in this investigation. Following that, it will be continued by examining the results of the models developed during the research. The fundamental model and model development with the stacking strategy approach were used as findings. After viewing the model's results, a comparison of various strategies in stacking containers in the stacking area will be made. The end result is an explanation of the comparative evaluation of the 3 stacking methods and their impact on container terminal productivity.

Parameter analysis was utilized to describe the aims of the research and the parameters used in this investigation. The goal of designing a container terminal model using a discrete-based modeling approach is to give a knowledge and evaluation of the performance of a container terminal based on a stacking strategy in the stacking area. The reshuffling process in the unloading process from the stacking area is the primary signal employed. Because the containers to be taken are blocked by other containers, this reshuffling is an action to unload heaps of containers.

After the simulation is completed, Plant Simulation can generate the following data relating to the above indicators:

1.   Number of Store Orders
This statistic displays the number of crane movements made in the stacking area to stack containers. This data displays how many containers enter each stacking area block. Because each store order represents one container stacking action. The reshuffling procedure is unknown in the container stacking process, hence each number of store orders indicates one container stacking activity.

2.   Number of Removal Orders
The number of removal orders represents the number of crane movements made while removing containers from the stacking area. Only after the container has been successfully removed from the stacking area is the value calculated. As a result, the number of crane orders indicates the number of containers leaving each block's stacking area.

3.   Number of Transfer Orders
This data indicates how many containers were transported to other stacks while unloading containers from the stacking area. Every crane movement that does not go to the head truck to be carried to the dock is calculated. In other words,

the number of transfer orders reflects the number of reshuffles caused by the stacking area demolition operation. The simulation results in Plant Simulation are shown in Figure 7.
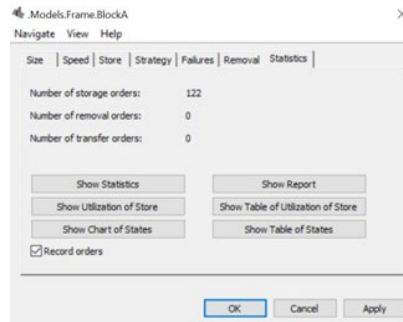

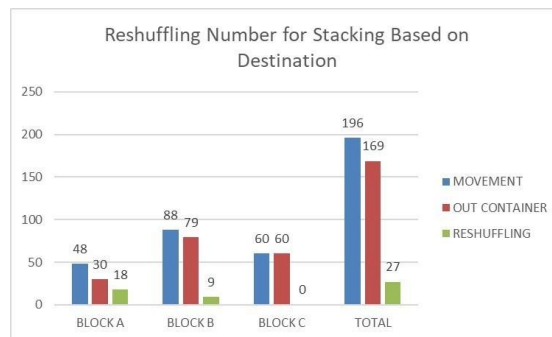Figure 7. Simulation Orders Result in Plant Simulation

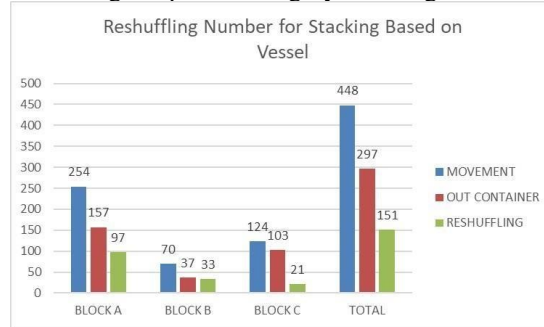Figure 8. Reshuffling Graph for Category Stacking Based on Destination

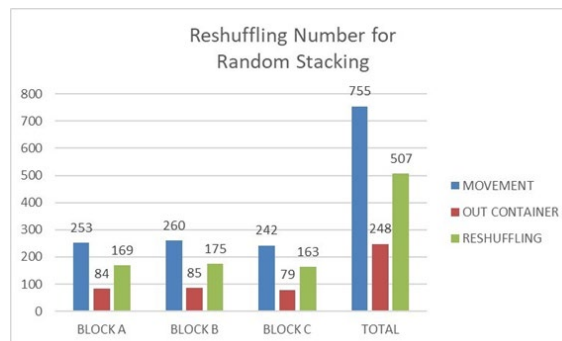Figure 9. Reshuffling Graph for Category Stacking Based on Vessel

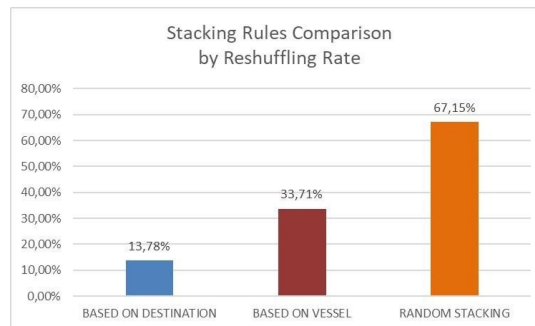Figure 10. Reshuffling Graph for Random Stacking
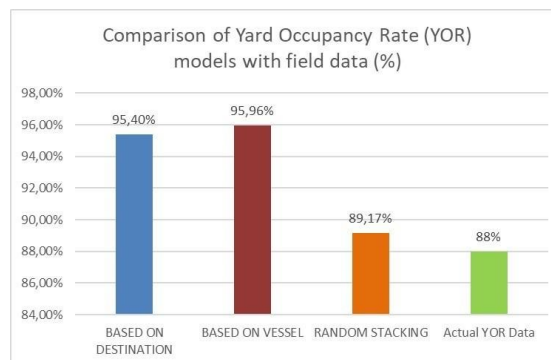
Figure 11. Reshuffling Rate Comparison Graph

Figure 12. Yard Occupancy Ratio Comparison Graph

Next, the final results of the simulation will be presented. The simulation data results will be per stacking block. Each model has 3 stacking area blocks. The results that will be seen at this stage are the number of reshuffling events per stacking block and the total number of crane movements for the unloading process of the stacking area. The results of the model are shown from Figure 8 to Figure 12.

The results of the Category Stacking Based on Destination model above show that reshuffling events only occur in 2 of the 3 stacking blocks. Reshuffling occurred by 37.5 percent in block A and 10.2 percent in block B. Meanwhile, in block C, no reshuffling occurred at all. The average total reshuffling in the Category Based on Destination model is 27 reshuffling out of 196 movements, which is 13.78 percent.

This little reshuffling activity suggests that emptying containers from the stacking area is an efficient activity. Almost every movement of the gantry crane is to transport containers from the stacking area to the stacking area. The results of the Category Stacking Based on Vessel model above show that reshuffling events occur in all stacking blocks. Reshuffling occurred at 38.18 percent in block A, 47.14 percent in block B, and 16.93 percent in block C. The total average reshuffling in the Category Based on Vessel model was 151 reshuffling out of 448 movements, which was 33.7 percent.

According to these findings, more than half of the gantry crane movements are for reshuffling operations caused by container stacking that is not in agreement with the operational design of the container terminal. The results of the Random Stacking model above show that reshuffling events occur in all stacking blocks. Reshuffling occurred at 66.79 percent in block A, 67.3 percent in block B, and 67.35 percent in block C. The total average reshuffling in the Random Stacking model was 507 reshuffling out of 755 movements, which was 67.15 percent.

These results indicate that about half of the gantry crane activities are for reshuffling. This certainly affects the length of time for unloading containers from the stacking area. Even in several stacking blocks, reshuffling activities are more numerous than activities to move containers onto the head truck.

The stacking rule Category Based on Destination has the lowest reshuffling rate (13,78%). The lower the reshuffling rate, the more efficient it is. Because reshuffling events reveal whether or not a container is stacked correctly in the

stacking area, the percentage indication for these events is the primary indicator. The percentage of reshuffling on the three models is contrasted in the table below. The % value given here represents the model's overall stacking block reshuffle percentage.

Yard Occupancy Ratio shows the performance data of stacking area utilization. In the Category Stacking model created in Plant Simulation, it can be seen that the area utilized in the model is larger than the real field YOR data. The model is then validated by verifying the present processes in the model with the model's conception. Verification begins by identifying the critical processes in the model and establishing whether they are operating in accordance with the model's conceptualization. The model activity verification is shown in Table 1.

No	Activity	Result
1	Truck arrival	Success
2	Installation of container attributes	Success
3	Stacking block allocation	Success
4	Unloading of containers from trucks	Success
5	The process of stacking containers	Success
6	Ship arrival	Success
7	Departure of the ship	Success

Table 1. Model Activity Verification

Depending on the model's final results in the preceding section, the three indicators used as a reference suggest that stacking containers based on ship characteristics delivers the best performance (Category Stacking Based on Destination). According to the three indications, the approach yields the least number, reflecting the efficiency of container unloading activities in the stacking area.

Essentially, the container unloading procedure will be tailored to the ship's arrival at the pier. Containers from ships that dock first will be unloaded first in the stacking area. As a result, it is critical to stack containers in groups based on the ship that will deliver them. So that containers from one ship do not mingle with containers from other ships. Finally, it will make unloading containers from the stacking area easier.

The model with the destination-based category stacking approach, on the other hand, does not stack containers in groups based on the ship that will convey them. Because stacking is solely determined by the container's function. Meanwhile, the containers are stacked randomly rather than clustered when seen through the ship's properties. Finally, there will be issues throughout the container unloading procedure. Because the containers will be picked up by the gantry crane in the sequence in which the ships arrive at the dock.

However, stacking approaches based on destination qualities are still relevant in the design of container terminal operations. In reality, aside from the arrival of ships anchored at the wharf, there is also a matter of planning for stacking on board at the container port (Stowage Planning). The destination of the container is the most essential component in stacking on board. Because the container with the most distant destination must be at the bottom of the stack. So that it does not obstruct the operation of loading and unloading containers at the next port.

As a result of an examination of the model architecture and container stacking simulation, it is possible to conclude that Category Stacking Based on Destination is the optimum strategy.

6. Conclusion
Researchers were successful in developing a discrete-event simulation-based container terminal model that represents the activity of loading and export containers from the time the container enters the container terminal to the time the container is transported on board.

The model was able to represent the process of stacking containers in the stacking area using three types of stacking methods: category stacking based on destination, category stacking based on vessel, and random stacking.

The category Stacking Based on Destination approach produced the least reshuffling activity, resulting in the maximum efficiency in container stacking activities in the stacking area. Reshuffling accounts for just 13.78% of total crane movement.

According to research, the category stacking approach based on destination has the highest performance since it creates the least amount of reshuffling. Other metrics, such as the number of gantry crane movements and the percentage of gantry crane movements, similarly reveal low values. So, in this model for the stacking yard approach, category stacking based on destination is superior to category stacking based on vessel and random stacking.

However, in order to develop operational activities for stacking containers that are more true with real-world settings, stowage planning concerns (stacking of containers on ships) must be taken into account. This model does not take these factors into account. As a result, the destination-based category stacking strategy can still have a considerable influence on container port operating performance. When discharging containers from the stacking area, the activity of stacking containers on ships is taken into account.

To be produced, extensive research on the operation of each container terminal is required. Because the container terminal's activities and operations are highly complicated. As a result, the researcher has some recommendations for the future development of this research. The use of Discrete Event Simulation software which is more up-to-date in terms of visualization in the future. The next model development is expected to be able to use other methods that are more complex and have more variables as consideration for container stacking methods such as Allocation Methods, Ship Queues, and Crane Placement. The development of the next model is expected to be able to incorporate other factors such as stowage planning and other factors for the complexity of container terminal operations. So that the model is able to more closely represent the container terminal in the real world.

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