SEMaTA (Sustainable Energy and Material at Tropical Area)
Journal homepage: https://talenta.usu.ac.id/semata

Design of Container Loading and Unloading Service Improvement with Simulation

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ARTICLE INFO

Article history:
Received : April 6th, 2026
Revised: May 28th,2026
Accepted: June1st, 2026
Available online September 11th, 2026

E-ISSN:
P-ISSN:

How to cite:
Amanda Reihan Sembiring Meliala, Humala Lodewijk Napitupulu, Ivo Andika Hasugian,"Design of Container Loading and Unloading Service Improvement with Simulation ", Junal SEMaTA (Sustainable Energy and Material at Tropical Area) Vol. 01, No. 04 , pp.32-41, September 2026.

ABSTRACT

Container congestion at ports is a growing concern due to the increasing annual throughput, which negatively affects service performance. To address this issue, it is important to accelerate loading and unloading activities. This study aims to improve port service quality by simulating container handling operations using Discrete Event Simulation and Activity Cycle Diagrams (ACD). The study was conducted at the Belawan Container Terminal by observing container operations such as unloading, transportation with Head Truck (HT), stacking with Rubber Tyred Gantry (RTG), and loading using Container Crane (CC). The actual operational model was replicated 10 times, and nine alternative equipment-mix scenarios were tested. Results show that Scenario 4, which involves reducing two HTs from the actual condition (resulting in 14 RTGs and 4 HTs), achieved the best performance. It improved service speed by 3.04 seconds per container and increased overall dock utility. These findings confirm that optimizing the equipment mix, especially balancing RTG and HT availability, significantly improves container handling efficiency and port performance.

Keyword: Container, Loading, Unloading, Simulation, Port Performance

1. Introduction

Sea transportation is one the important roles in improving the country's economy, about 74.3% of Indonesia's area is water and sea. Indonesian marine waters cover an area of 1.5 million km2, covering 0.3 million km2 of the territorial sea, 2.8 million km2 of archipelagic waters, and 2.7 million km2 of exclusive economic zones. The large area of Indonesian waters makes the sea one of the most important distribution and transportation routes today. Sea transportation requires infrastructure in the form of ports in its implementation. Sea and port transportation is one of the transportation sub-sectors that is also an important part of supporting community activities [1]. A port is a water area protected against waves equipped with marine facilities that include a pier where ships can propagate for loading and unloading goods, cranes for loading and unloading goods, sea warehouses (transit) and storage areas where ships unload their cargo, and warehouses where goods or crates containers can be stored for a long time while waiting for delivery to the destination or shipment [2]. A Container is a package used to transport and store cargo that is specially designed with a specific size and used repeatedly. Containers can wrap and make all loads into one unit so that they can carry them safely, quickly, and efficiently or maybe the door to door [3]. A container terminal is a meeting place between land transportation that adheres to a unitization system (Union of Cargo System), containers as warehouses or containers, transportation means served by Container Terminals/Ports. The functions of the Container Terminal are: A place for loading and unloading containers from ships to trucks and vice versa, packing and unloading containers, supervising and guarding containers and their cargo. Receiving fleets of ships, cargo handling services for containers and their container yards [4].

Terminal Peti Kemas Belawan (TPKB) is a container terminal that serves container loading and unloading activities. Loading and unloading is an activity to unload goods from the ship to the nearest dock or land from the ship's edge using loading and unloading equipment such as lorries and cranes that are then arranged and put into the closest storage area [5]. The flow of loading and unloading from the TPK Belawan that include in Figure 1. Based on that, it can be seen that the flow of loading and unloading of containers continues to increase from year to year from 2017-2020 and has incremented by 10.79% in Semester 1 2021 compared to the same semester in the previous year with a total of 717,030 TEUs.

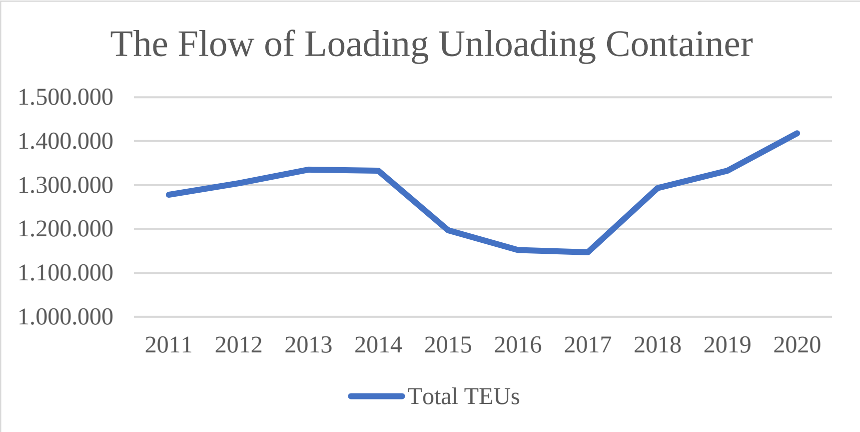


Figure1. The Flow of Loading Unloading Container

The loading and unloading process at the port is one of the dominant factors that affect the performance of a port. The duration of the loading and unloading process at the port also has implications for the length of a ship's turn round time, that was mean makes the ship's operational costs more expensive. The problem is the length of the ship's service time because it is necessary to improve the service system to improve service performance.

Simulation is one of the methodologies used to model the system from the real system by conducting experiments. Simulation is to save both costs, time, and energy. This can be done because it is not directly implemented on the flame system so simulations can be carried out first [6]

The depiction of the real system is used Activity Cycle Diagram (ACD). ACD is a method to describe the interaction between objects in a system. This diagram provides a graphical modeling notation to describe a series of activities in a variety of real-life situations [7]

Research analysis of the queuing system for cargo ships at the Port of Tanjung Perak Surabaya (Ahmad & Mashuri, 2015) shows that optimal service can achieve by changing loading and unloading activities and being able to increase system utility at several existing docks [8]

The results of other research conducted at the Port of Tanjung Priok regarding modeling and optimization of the container's queues show that the use of optimum handling equipment will minimize the number of queues in each state [9]

Research conducted at the Trisakti Port of Banjarmasin regarding the optimization of the allocation of export container stacking fields using the Software Arena (Setyo Nugroho et al., 2020) showed the results of evaluation and optimization at the Container Yard, namely reduced truck mileage up to 4%, the efficiency of container allocation in the stacking block. (CY) by 55% and ship block by 74%, saving on loading time by 13%, and savings in total fuel costs from trucks, RTG, and CC by 16% [10]

The focus of this research is to increase the utility of the actual container loading and unloading service system based on the Head Truck (HT) service time and the Rubber Tyred Gantry (RTG) service time, with several scenarios. The difference between this study and previous research is the use of Software Arena in simulating the loading and unloading business process of containers at the TPK Belawan.

2. Method

The type of research carried out is simulation research. It is a form of study that aims to find an overview through a small or simple scale system in which the model is manipulated or controlled to observe its effects. Although similar to experimental research, the main difference lies in the need for an environment that resembles the actual system being studied. The study was conducted at the Belawan Container Terminal, located on Jalan Raya Pelabuhan Gabion, North Sumatra, in March 2022. The observed object was the container loading and unloading activities at TPK Belawan.

2.1 Research Design

The observations were carried out on the loading and unloading container operational activities starting from the arrival of ships, the process of loading and unloading containers using CC, the process of haulage with HT, transportation of containers from and to CY, stacking of containers using RTG, the process of receiving containers at CY, to ship departure.

2.2 Data Collection and Processing

The method of analyzing observational data using the ARENA software includes descriptive analysis and fit-testing of the distribution pattern of opportunities or the frequency of loading and unloading service rates. Likewise, the simulation data processing in the ARENA Software takes place using the container loading and unloading process model designed on the process analyzer. Simulations are run for each alternative scenario of the number of equipment used, like RTG and HT. Data collection in this study was carried out by direct observation of the object of research. The results of this observation are from arrival time of the ship and the time of container services. Data collection by time study using a stopwatch on units of loading and unloading activities. The tool used to find out the real picture of the system under study uses a conceptual model design. The conceptual model designed will be represented in a simulation model. Conceptual model design using Activity Cycle Diagram (ACD), ACD data processing is to see how many entities are in the system. ACD in the unloading process can be seen in Figure 2. and ACD in the loading process can be seen in Figure 3.

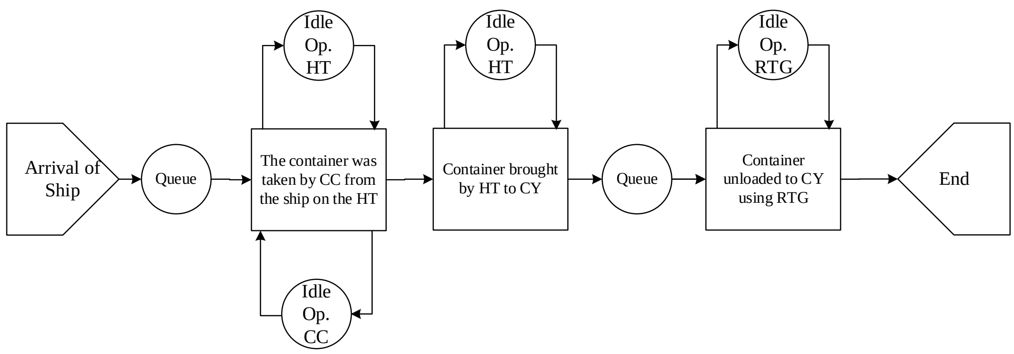


Figure 2. Activity Cycle Diagram of Unloading Container

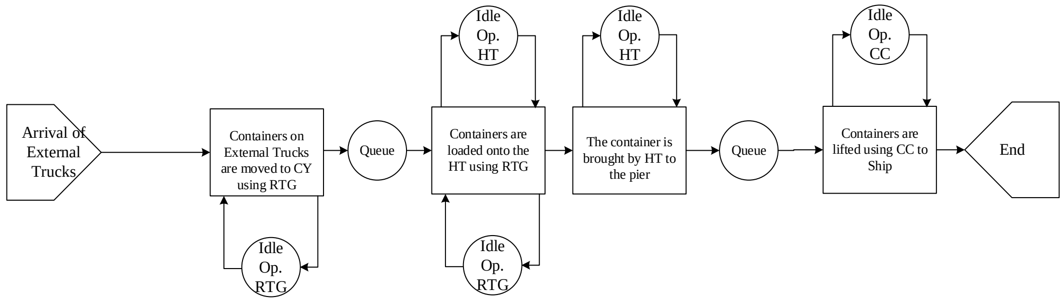


Figure 3. Activity Cycle Diagram of Loading Container

2.3 Simulation Modeling

After designing the conceptual model, a simulation design was carried out with the following conditions: the design of the simulation model under actual conditions was based on the previously constructed conceptual model. Based on the conceptual model, the input data for the simulation was obtained, namely, the number of loading and unloading loads for each container, Container Crane (CC) service time, Rubber Tyred Gantry (RTG) service time, and truck speed. These data were processed using the Input Analyzer in Arena Software to determine the appropriate distribution patterns for ship arrivals, number of containers, and equipment speed. The algorithm used in the process of transporting containers from the ship to HT or vice versa can be seen in Figure 4. The algorithm in the process of transporting containers from CY to HT or vice versa using HT can be seen in Figure 5. After that, the final simulation model design was carried out as shown in Figure 6 as taken by CC from the ship onto the HT.

There are 91 modules used in modeling the loading and unloading process for containers with a running time of 10 replications and a maximum runtime of 9 minutes per replication. After modeling, simulations can be made in 2D form. The 2D simulation before running is shown in Figure 8, and the 2D simulation after running is shown in Figure 9. Based on the running results, it can be seen that the unloading blocks such as Block A, Block B, and Block C have been filled, and the loading block is empty, which means that it has been transported to the ship and the ship has already experienced departure.

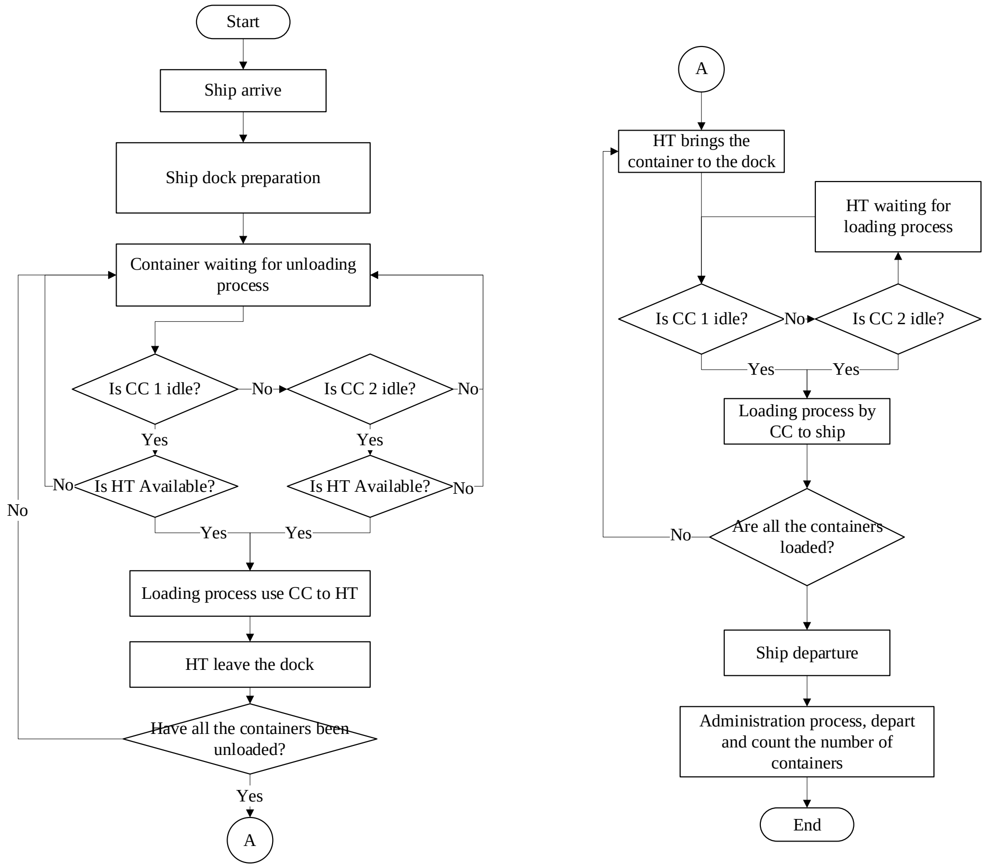


Figure 4. The Algorithm Transporting Process Using CC

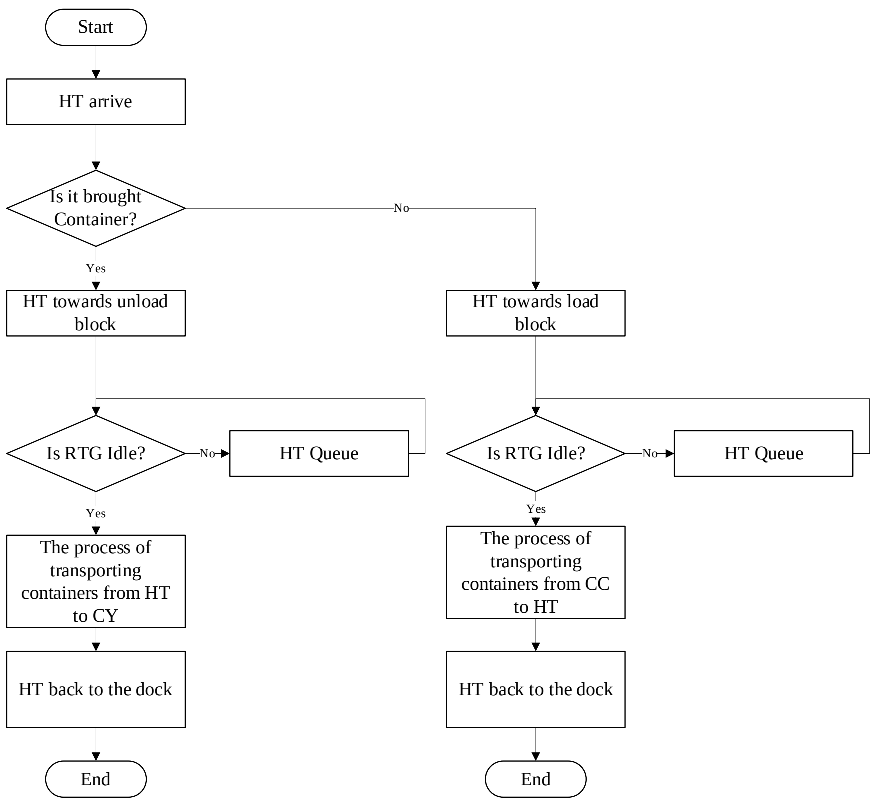


Figure 5. The Algorithm Transporting Process Using RTG

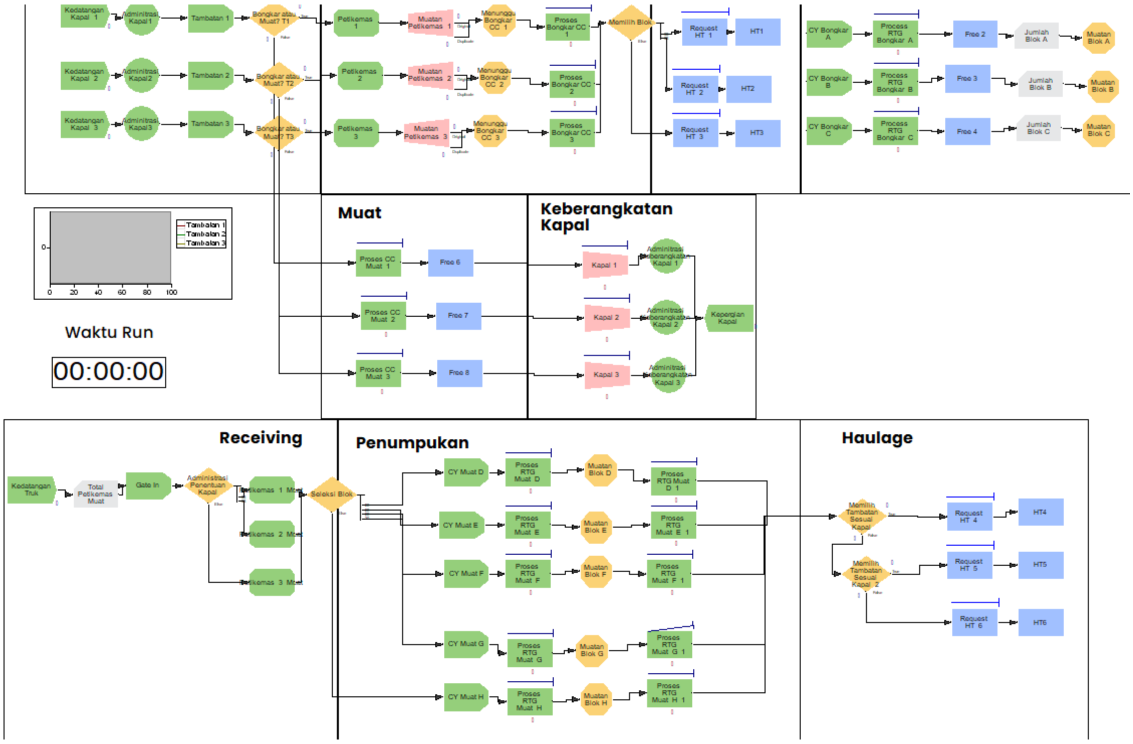


Figure 6. Final Simulation Model of Loading Unloading Container Process

2.4 Validation

Validation is done to compare the real conditions with the simulation model results. In this loading and unloading process, the number of containers and the number of ships served is compared. Replication was carried out 10 times in the validation process. The number of containers at the nth replication was compared to the output in the current real system.

A simulation model is declared valid if it passes the validation test. Validation tests are carried out to ensure that there is no significant difference between the simulation model and the actual system. The method used to validate is Welch's t-interval, which is used to determine whether there is a significant difference between the population and other populations. Since replication runs use randomly generated input data, the output may vary depending on the generated values.

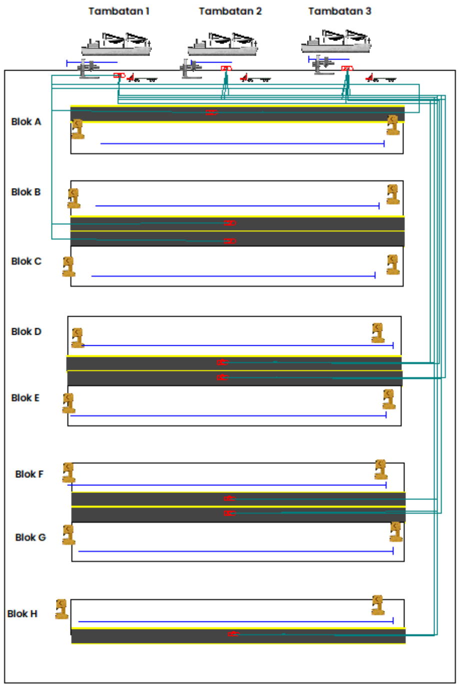


Figure 8. 2D Simulation Before Running

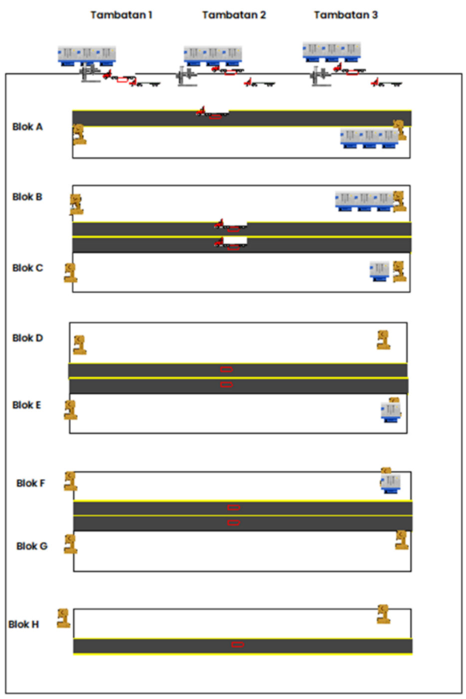


Figure 9. 2D Simulation After Running

3. Results and Discussion

3.1 Simulation Results with Actual Conditions

Simulation modeling under actual conditions was carried out using Arena Software with 10 replications as samples. Then calculate the average of the 10 samples. The average of the results of the replication is then used as material for discussion. The utility of each tool used in container loading and unloading operations at TPK Belawan was evaluated. The average utility of Container Crane (CC) is quite high at 66.75%, but in CC each tether has a utility value that is quite far. The difference in CC utility which is quite far is caused by the use of CC depending on the location of the tether. The use of loading and unloading blocks depends on the priority and order of block priority and the number of containers loaded by each ship. The average utility of RTG is sufficient with a value of 36.00% while the utility of HT is classified as moderate at 51.00%. After 10 times replication, the average number of containers served by Terminal 1 is 460 containers, Terminal 2 is 832 containers and Terminal 3 is 1168 containers. The number of container flows is influenced by the distribution of the number of ship containers used in the model. The distribution is based on service time data obtained from the Belawan TPK. The distribution determines how many containers are carried by one ship.

3.2 Simulation Results with Scenarios

Based on the simulation with 9 scenarios and the difference in the number of RTG and HT levels with 3 different levels, we get a comparison of HT utility, CC utility, RTG utility, service speed, dock utility. Comparison of HT utilities can be seen in the following figure.

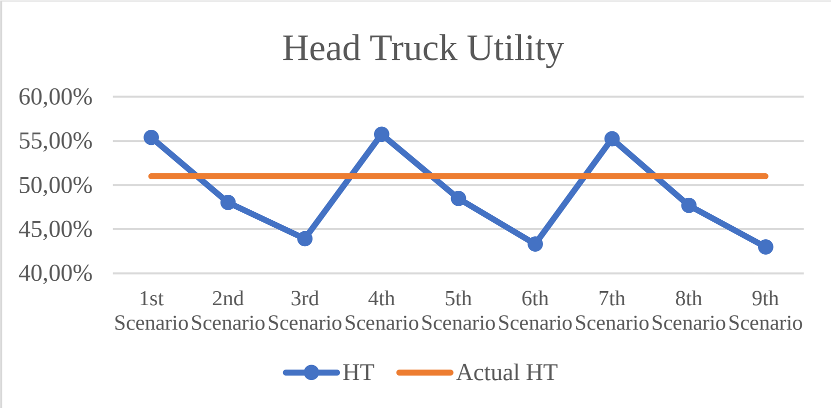


Figure 10. Head Truck Utility Comparison

Based on the graph above, it can be seen the utility of Head Truck in each scenario. The highest HT utility value is in scenario 4 with 14 RTG and 5 HT at 55.74%. The HT utility in scenario 4 is 4.75% higher than the actual model. The lowest HT utility value is found in scenario 9 of 43.00% with 15 RTG and 6. Idle HT. A comparison of CC utilities can be seen in the following figure.

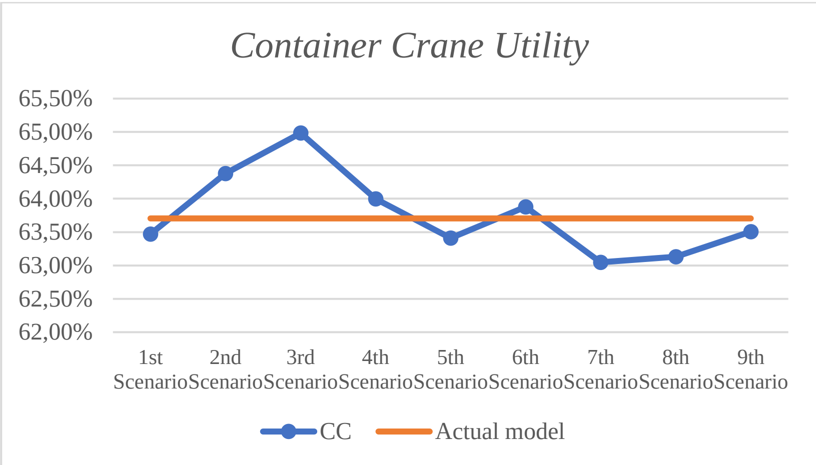


Figure 11. Container Crane Utility Comparison

Based on the results of the scenario, the addition of appropriate HT can increase the utility of CC, in the process CC requires HT to process so that the amount of HT greatly affects the utility of CC. The comparison of RTG utilities can be seen in the following figure.

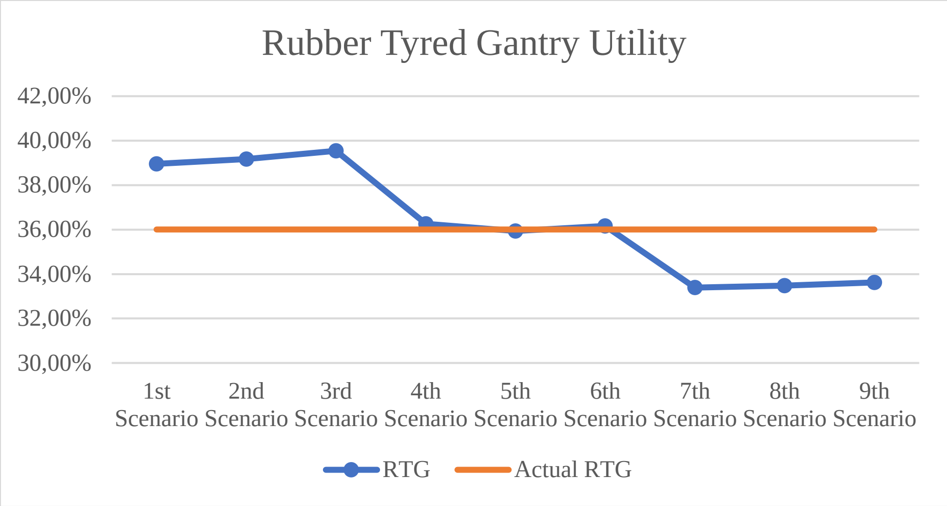


Figure 12. Rubber Tyred Gantry Utility Comparison

The highest RTG utility value is in the 3rd Scenario (13 RTG and 6 HT) with a value of 39.54%, the value is 3.54% greater than the actual model. The lowest RTG utility value is in the 8th Scenario (15 RTG and 5 HT) with a value of 39.54%. Based on the results of the scenario, it can be seen that the addition of RTG will reduce the utility value of the RTG, the more RTG, the more idle time in each RTG. This is due to the number of containers that do not increase along with the increase in the number of RTGs.

The speed of service is obtained from the comparison of the average number of containers served with the average time of service. The speed of service can be seen in the following figure.

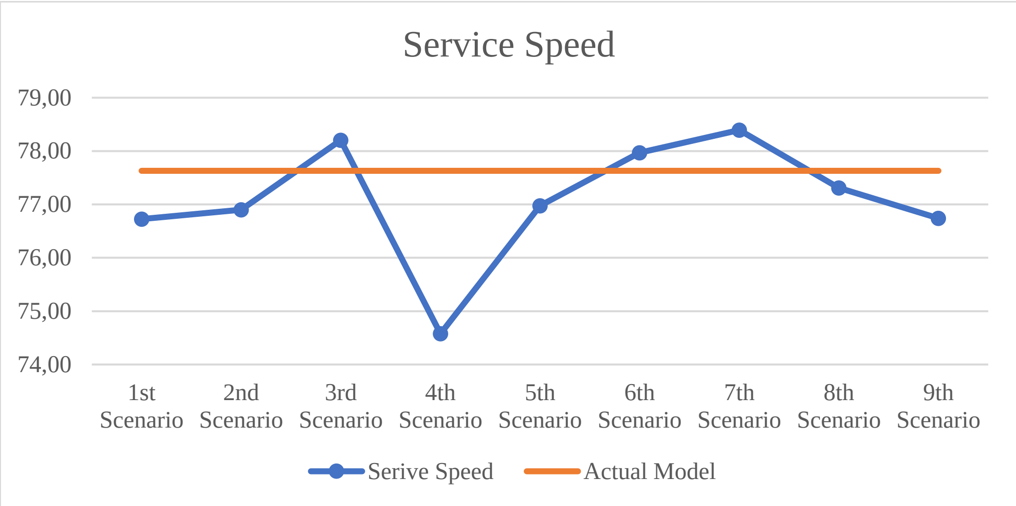
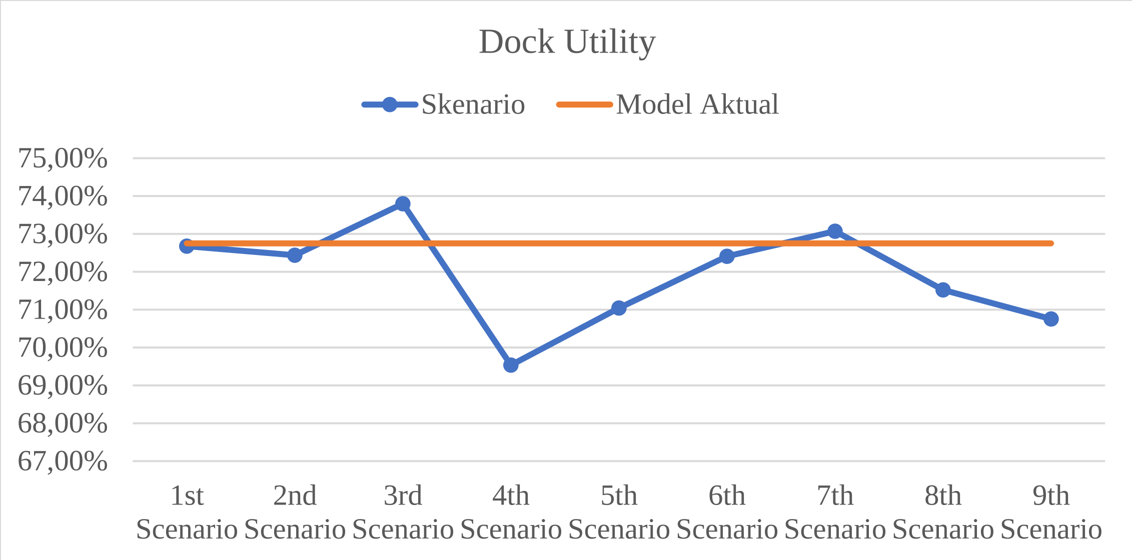


Figure 13. Service Speed Utility Comparison

It can be seen that the fastest Service Speed value is in Scenario 4 (14 RTG and 4 HT) of 74.58 seconds/Box. The longest service speed is in scenario 3 (13 RTG and 6 HT) of 78.20 s/TEUs. The value of service speed is influenced by the number of containers per ship and the speed of loading and unloading equipment. Based on this, it can be seen that the addition of the appropriate RTG and HT will increase the speed of service from the wharf. The average service speed increased by 3.05 seconds/Box by reducing 2 Head Trucks. The dock utility is obtained from the comparison of the service time with the total time. The comparison of the dock utility between scenarios can be seen in the following figure.



Gambar 14. Comparison of Dock utility

The smallest dock utility value is owned by scenario 4 (14 HT and 4 RTG) with a value of 76.65%. While the value of the largest wharf utility is in scenario 3 (13 RTG and 6 HT) with a value of 80.92%.

4. Conclusion

1. The conceptual model of the loading and unloading process of containers at the Belawan Container Terminal is described using the Activity Cycle Diagram in showing the sequence of process activities from the system starting from Ship Arrival - unloading process - haulage process - container stacking process loading and unloading of trucks - loading and unloading of containers - haulage process - loading process - ship departure.
2. The simulation model is described using a logical model using Arena Software to assign the module to make movements according to the conceptual model. There are 91 modules used in the simulation. It takes 9 minutes to run the simulation model with 10 replications for 24 hours. Software Arena experimental simulation by considering the number of RTG and HT,
3. The best scenario that can be suggested based on the speed of service and dock utility is scenario 4 with a total of 14 RTG and 4 HT per pier. Reducing the number of Head Trucks by 2 can increase the service speed, improving it by 3.04 seconds per box.

5. Acknowledgements

The authors would like to express their sincere gratitude to all individuals and institutions who have supported the completion of this research and the preparation of this journal article. The authors also thank the management and staff of Belawan Container Terminal for their cooperation during data collection. Lastly, sincere thanks are given to family and friends for their continuous encouragement and motivation during the writing of this paper.

6. Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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