Container terminal landside operation analysis and discrete event simulation in container terminal in port: a case study of Terminal 3 Ocean-going PT Pelabuhan Tanjung Priok

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Abstract. This study discusses the landside operation and presents the application of Truck Appointment System (TAS) and lane segmentation strategy through discrete event simulation in Terminal 3 Ocean-going PT Pelabuhan Tanjung Priok. This study aims to analyze the operation planning system in Terminal 3 Ocean-going and identify problems that exist on terminal 3. This study also seeks to examine the landside operation process and offer alternative scenarios to solve the congestion problem in the terminal. Alternative scenarios provided are a combination of Truck Appointment System (TAS) and lane segmentation strategy. Truck Appointment Strategy (TAS) with 100% utilization is proved to reduce average total time in the system by 76% and reduce average total time in peak days by 88%, from 151.5 minutes to 38.4 minutes per truck. Truck Appointment System (TAS) is also proved to reduce queue length by 97%, from 162 trucks to 5 trucks.

1. Introduction

Shipping lines and seaport holds an essential part in global trade. According to UNCTAD (2017) [1], more than 80% of global trade volume and more than 70% of global trade value are transported through maritime transportation. In 2016, global trade through maritime transport increases by 2.6%, improved from 1.8% growth in 2015. Total volumes reached 10.3 billion tons in 2016, including the increase of more than 260 million tons of cargo. The total volume consists of 3.1 billion tons of tanker trade (oil and gas), and 7.2 billion tons of dry cargo. Containerized trade contributes 23.8% of dry cargo shipments, convert to 1.72 billion tons of containerized shipments. According to UNCTAD (2017) [1] in 2016, containerized trade has 3.1% growth with a total shipment of 140 million 20-foot equivalent unit (TEUs). Based on the throughput volume in the container port, Asia dominated global trade with 64% of global trade volume. 64% of global trade volume is distributed, mainly from countries in East Asian and South East Asia. The rest of the global trade are divided into Europe with 16%, North America with 8%, Developing America with 6%, Africa with 4%, and Oceania with 2%.

Seaports are strategically crucial for industrial activity, trade, global production, and economic growth. Indonesia’s most important ports rank much lower than the neighboring countries such as Singapore and Malaysia [2][3]. Port of Singapore has a throughput of 30.9 million TEUs, becomes the second biggest port in the world based on throughput. Malaysia’s biggest port and its second biggest port, which is Port Kelang and Port Tanjung Pelepas, have a throughput of 13.1 million TEUs and 8 million TEUs and are ranked 11th and 19th. Indonesia biggest port, Port Tanjung Priok
has a throughput of only 5.5 million TEUs, which make it the 26th biggest port based on throughput [1].

This study aims to reveal the problems at Terminal 3 Ocean-going and examine the current situation for viable improvement based on the low throughput compared to other ports. Based on the problems analysis, this study demonstrates the implementation of a truck appointment system (TAS) as a recommendation to improve the performance of the landside operation in Terminal 3 Ocean-going. For this purpose, this study determines the activities and process required in landside operation in Terminal 3 Ocean-going. Those activities and process are translated into a discrete-event simulation using Arena simulation software. The simulation is used to assess the current situation at Terminal 3 Ocean-going landside operation and to simulate the implementation of alternative scenarios.

2. Literature review

We review the literature based on the interlinked subjects; these are terminal operations in each area, strategies to reduce congestion at the terminal gate and discrete event simulations. Operation areas of container terminal consist of four areas, namely berth area, transport area, yard area, and hinterland area. Operation process on hinterland area is the transport process outside of container terminal, consist of transporting container from the hinterland to terminal and from the terminal to the hinterland. Transportation between hinterland and terminal were done with external transportation such as trucks or trains [4][5].

2.1. Operation areas: berth, transport, and yard

The berth area is a place to vessel berthing and container handling process between vessel and terminal. Operation of the container handling uses quay cranes. Quay cranes are used to move import container from vessel to internal truck and move the export container from internal truck to vessel according to the operation plan. Operation on the transport area consists of two operations, which is transport between berth area and yard area and transport between yard area and gate area and to the hinterland. The first one uses internal trucks to move between the berth and yard area. Transportation between the yard area and gate area uses external trucks to transport containers between these areas. Yard areas are used as temporary storage for containers before being sent to their destinations. A yard area is a buffer area to connect between different or same mode of transportation, for example between water and land transportation. A yard area is divided between several blocks according to its use, e.g., export or import containers. These blocks are marked with lines to determine places where containers can be positioned within those blocks. There are some spaces between blocks dedicated to truck lanes and for handling operation between trucks and yard cranes [6][7].

2.2. Strategy to solve congestion at the port container terminal

The port of California implements 24 hours of operation at its container terminal to reduce congestion during peak hours [8]. The purpose of this strategy is to disperse volumes during peak hours to off-peak hours such as early morning or midnight when the terminal is still open for operation. Another strategy applied at other container terminal is to implement a time-varying toll charge [9]. This strategy applies a toll charge for every truck entering the terminal. This strategy is utilized to force trucks switching their schedules to off-peak hours with low toll charge or even free of charge [10]. The next strategy is to implement a truck appointment system (TAS) [11][12]. With this strategy, the terminal implements a booking system for every truck to use. Every truck entering the terminal must use the booking system and booking available time slots in the system. Every time slot has a one-hour interval. Trucks must arrive at the terminal within those interval time. There will be an additional charge for trucks passing the time interval; they cannot enter the terminal when longer than 15 minutes behind schedule and must book another time slot. There will be limited capacity for each time slots based on the terminal’s volume during those hours. This strategy is used to disperse truck volumes to available time slots which mainly during off-peak hours.
TAS implementation is usually combined with another strategy such as lanes segmentation. Lanes segmentation divides existing terminal gate based on types of containers such as general containers or reefer containers. This strategy can also be used to divide terminal gates into the gate for trucks using TAS and the gate for trucks not using TAS. This strategy offers another incentive for trucks to use TAS [8].

3. Research methodology

This study utilized exploratory study to identify and analyze problems occurs in the Terminal 3 Ocean-going and descriptive study to assess the benefit of implementing a truck appointment system and lanes segmentation to Terminal 3 Ocean-going [13]. Simulations in this study adopt the research model from Li, Wu, & Goh (2015) [14] to examine problems occurs at container terminals based on operation areas and the research model from Gracia et al. (2017) [8] to examine truck appointment systems and lanes segmentation implementation in Terminal 3 Ocean-going.

This study is conducted from January to May 2018 starting from primary and secondary data collection followed by the data analysis and discussions. This study utilized in-depth interviews with control and planning division of PT Pelabuhan Tanjung Priok and representatives of Terminal 3 operator division. Data related to the organization and business processes or activities are collected as well, such as truck arrival and distribution. The duration of each activity in the landside operation is collected using observation method in the terminal area.

The obtained data related to operation problems occur at Terminal 3 Ocean-going are analyzed qualitatively. Moreover, we examine the data to construct discrete event simulations using Arena 14 to simulate the implementation of a truck appointment system and lanes segmentation at Terminal 3 Ocean-going [15][16]. The simulation model focuses on operation process simulation of container trucks in the terminal regardless of their activities in the terminal (carrying or acquiring containers).

4. Results

Based on in-depth interviews and observations at the terminal area, we identify and analyze several prevailing problems at the Terminal 3 Ocean-going according to every operation planning area in the terminal. These problems arise due to many causes, such as undisciplined operators at the terminal, lack of coordination between area and between terminal operator and its stakeholders, and problems from its stakeholders’ requirements.

Table 1 shows the problems identified in this study. Arguably, we determine two critical problems requiring solutions drawn from interviews and observation analysis. The first problem is the limited yard space. When the yard area cannot support the berth area, then the berth area has limited productivity percentage depending on how much yard area can support. When the terminal operator predicts that yard area will be over capacity when the next ship arrives, some of the containers need to be moved to another area called Lini 2. This movement requires time for coordination between division and equipment mainly yard cranes and trucks which could be used for something more productive.

The second problem is the congestion in the terminal when there is a massive volume surge. This problem usually occurs every Friday to Sunday when the volume decreases again. This sudden increase is caused by the weekly cycle that occurs in this terminal. Friday and Saturday are the time when most of the ship arrives at the terminal, so most container owners will transport their containers to the terminal when the ship arrives on Friday or Saturday. The congestion makes landside operations in the terminal a lot longer than usual. This congestion also disrupts access to terminal 2 since the queue line are stretched to terminal 2 gates.

Furthermore, this study focuses on analyzing the implementation of a truck appointment system and lanes segmentation to reduce and solve the congestion problem occurs in Terminal 3 Ocean-going. By implementing these strategies, the terminal operator can disperse truck volumes on peak hours to off-peak hours and from peak days (Friday-Sunday) to off-peak days (Monday-Wednesday).

The landside operation process for external container trucks at Terminal 3 Ocean-going is divided into three parts, namely the customs gate, terminal gate, and yard area. Before trucks can enter the
terminal, they need to prepare the required documents based on their containers, shipping export containers or take import containers. Those documents will be checked at the customs gate, and the terminal gate, and both gates will update the container status on their system. After the truck has passed the arrival gate, trucks will start their container handling processes at the yard area. Finally, trucks will need to pass through the terminal and customs gates again to document the transactions and update the status on the terminal system once again.

Table 1. Identified Problems in Terminal 3 Ocean-going and Alternative Solutions

| Problem Area                      | Problem Description                                                                 | Alternative Solution                                      |
|-----------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------|
| Terminal Area                     |                                                                                      |                                                           |
| Terminal Design are not compatible| Initially, Terminal 3 designed as a multifunction terminal, so the terminal did not have enough yard area to support its berth area | Add more yard area in Lini 2                             |
| Congestion in Terminal Gate       | Congestion happened because of truck volume increase exponentially                   | Implementing a truck appointment system and lanes segmentation |
| Limited crane operator            | Crane operator did not provide enough to support when there is a high volume in the terminal. Terminal need time to add more operator to help its operation | Implement detailed operation schedule for every operator according to volume trends |
| Operator in the terminal gate is not discipline | Gate operator is not disciplined in changing the container status in the terminal’s system | Implement a system to change container status in the terminal automatically |
| The equipment is broken           | There are two quay cranes and one yard-crane broken                                  | Fix or replace the equipment                              |
| Berth Allocation Area             |                                                                                      |                                                           |
| Ship delay enter to the terminal  | Delay caused by unfinished document or insufficient export container in the terminal | Remind the shipping lines to prepare all documents required |
| Ship delay when departure from terminal | Delay caused by unfinished container operation in the ship                         | Monitoring closely in the operation process               |
| Unscheduled ship arrival         | Majority of the ship will be berthing in Terminal 3 Ocean-going unscheduled          | Make a partnership with shipping lines to make berthing scheduled date |
| Yard Planner Area                 |                                                                                      |                                                           |
| Uneven yard area                  | There are uneven floors in some parts of the yard                                   | Fix uneven floors when occurred                           |
| Ship Planner Area                 |                                                                                      |                                                           |
| Planning process requires much time and depends on the planner | Long planning time cause the whole planning to become long too and the time and quality of the plan heavily depends on the planner | Implement a system to assist or to make the plan needed for terminal operation |
| The difference in EDI and CVIA file | EDI and CVIA document received did not have the same number of containers           | Remind the shipping lines to check the documents before sending it to the terminal operator |

Next, the simulation model has several assumptions to produce a precise output. These assumptions are as follows:

a. The container truck arrival data examined in this study consist of truck arrival data at Terminal 3 Ocean-going from 23-29 April 2018, i.e., truck arrival data for one week.

b. The process duration for each activity is collected through observation at Terminal 3 Ocean-going
c. The simulation period on every scenario is run for a week or 168 hours based on the arrival data being used.
d. Each scenario is replicated ten times.
e. The α value being used for the validation test is 5%.
f. All lanes are assumed to be empty at the beginning of the week.
g. Terminal 3 Ocean-going operates for 24 hours and is divided into three shifts.
h. All equipment is only used for the landside operation process of the truck at the terminal.
i. The operation activity at the terminal is stopped at 04:00-05:00, 07:00-08:00, 12:00-13:00, and 18:00-19:00 each day.

Table 2. The Output of the Validation Test on the Base Case Scenario

| System Output (Truck) | Mean  | Standard Deviation | T_{9,0.25} | Confidence Interval | Upper Tail | Lower Tail | Real System Output |
|-----------------------|-------|--------------------|------------|--------------------|------------|------------|-------------------|
|                       | 5,659 | 76.53              | 2.262      | 95%                | 5,825      | 5,492      | 5,666             |

After running the simulation, the output is then validated using a test with a specific confidence interval to compare the simulation model output and the real system output. The validation test uses a 95% confidence level and an α value of 5%. The test output is shown in Table 2. The parameter used in this test is the truck output from the system for a week. A simulation model is constructed using this output which replicates a real system with an output of 5,666 within the model simulation confidence interval of 5,492-5,825 trucks. Furthermore, the simulation model can be used to simulate the implementation of strategies in the system.

In this part, we illustrate the TAS and segmentation implementation through five alternative scenarios. Scenario 1 will implement a 15% utilization of TAS, and another 85% truck still use the existing system. In Scenario 2, it applies 15% utilization of TAS and lanes segmentation in the form of adding one arrival terminal gate exclusive for truck using TAS booking system. For Scenario 3, it increases TAS utilization to 40%. Scenario 4 is similar to Scenario 2, besides 40% utilization of TAS; it also adds one more arrival terminal gate. In Scenario 5, the utilization of TAS become 100% utilization.

Table 3. The Output of Paired-T Test between the Base Case and Alternative Scenarios (Hours)

|                      | Base Case | Scenario 1 | Scenario 2 Non TAS | Scenario 2 TAS | Scenario 3 | Scenario 4 Non TAS | Scenario 4 TAS | Scenario 5 |
|----------------------|-----------|------------|--------------------|----------------|------------|--------------------|----------------|-----------|
| Mean                 | 10.98     | 7.54       | 8.05               | 7.3            | 4.19       | 4.82               | 4.16           | 1.85      |
| Std Dev              | 1.58      | 0.77       | 1.24               | 1.37           | 1.66       | 0.51               | 1.39           | 0.13      |
| Upper Tail           | 4.28      | 4.19       | 5.04               | 7.82           | 7.15       | 7.81               | 10.19          |           |
| Lower Tail           | 2.59      | 1.66       | 2.32               | 4.88           | 5.15       | 5.82               | 8.05           |           |

Statistically Significant
Each alternative scenario is tested with Paired-T test to examine its differences to the base case scenario. Table 3 shows the output of Paired-T test on alternative scenarios. Every alternative scenario is significantly better than the base case scenario. In Scenario 2 and 4, the output differentiates trucks using TAS and trucks not using TAS. The parameter used on this test is the average total time needed in the system.

5. Discussion
By running simulation, we can conclude that TAS and lanes segmentation can reduce congestion at Terminal 3 Ocean-going significantly based on the Paired-T test. The parameters used in this study are the average total time needed in the system and the average truck queue length in the system. The average total time in the base case scenario can be reduced in each alternative scenario; Scenario 5 generates the most significant reduction. Scenario 1 can reduce the average total time by 34% from the base case scenario. Scenario 2 is proved to provide incentives to trucks using TAS with a decrease in average total time of 40% from base case scenario compared to trucks not using TAS with a decrease of 29% from the base case scenario.

Furthermore, Scenario 3 can reduce the average total time by 58% from the base case scenario. Scenario 4 is also proved to provide incentives to trucks using TAS with an average reduction in total time of 65% compared to trucks not using TAS with a decrease of 60%. Scenario 5 shows that if the TAS is 100% used by all trucks entering the container terminal, the average total time reduction is 76%.

The reduction of total time on congestion in the terminal will be better if we see from the average total time from Friday to Sunday because it focuses on peak days at the terminal. Scenario 1 can reduce the average total time by 38%, and Scenario 2 reduces the total time by 43% for trucks using TAS and 32% for trucks not using TAS. Furthermore, Scenario 3 can reduce the average total time in all three days by 65% while Scenario 4 can reduce the average total time by 72% for trucks using TAS and 67% for trucks not using TAS. Finally, Scenario 5 can reduce the average total time for three days by 88% from the base case scenario.

The average reduction in total time is due to the transfer of truck volume during other days such as Monday to Thursday when there is no truck buildup in the terminal. Figure 1 depicts a comparison between the base case scenario and the alternative scenarios; the average total time for Friday, Saturday and Sunday have decreased in each alternative scenario while the average total time for Monday, Tuesday, Wednesday, and Thursday has experienced an increase in some scenarios, especially in Scenario 5. This result occurs as the result of the transfer of truck volume in the base case scenario from Friday to Sunday; in the alternative scenario, it is switched to Monday to Thursday using TAS with an amount based on each scenario each is 15%, 40%, and 100% use of TAS.

![Figure 1. Average Total Time for every Scenario](image-url)
In the figure above, the use of 100% TAS can provide the most significant time reduction compared to other scenarios with a decrease in the total time of the week by 76% and a decrease in the average total time for Friday to Sunday of 88% from base case scenario.

Lanes segmentation strategy in the form of adding lanes specifically for trucks using TAS is proven to provide additional incentives for trucks using TAS. In Scenario 2, trucks using TAS have an average total time for Friday to Sunday of 184.4 minutes, decrease by 17% from trucks not using TAS where the average total time for Friday to Sunday reaches 221.2 minutes. In Scenario 4, the differences between trucks using TAS and those not using TAS decreased to 15%. Trucks using TAS have an average total time for Friday to Sunday of 91.8 minutes compared to trucks that do not use TAS for 108 minutes.

Figures 2. Maximum Total Time among All Scenarios

In Figures 2, the maximum total time in the landside operation process at Terminal 3 Ocean-going for base case scenario and alternative scenarios. In the base case scenario, the highest total time is 12.92 hours for one truck. This amount can be reduced by alternative scenarios that have been made. Scenario 1 can reduce the highest total time by 31% from the base case scenario. In Scenario 2, the maximum total time can be reduced by 26% for trucks using TAS and 25% for trucks not using TAS.

Furthermore, Scenario 3 can reduce the maximum total time by 57% from the base case scenario. While Scenario 4 can reduce the maximum total time by 60% for trucks using TAS and 55% for trucks that do not use TAS. Scenario 5 can reduce the maximum total time by 84%, from 12.92 hours in the base case scenario to 2.02 hours.

Lanes segmentation strategy does not give a significant difference between trucks using TAS and those not using TAS in Scenario 2. Trucks that use TAS have a maximum total time faster by 1% from trucks that do not use TAS. Different results are shown in Scenario 4. The maximum time difference between trucks using TAS and trucks that do not use TAS is 11%. Trucks not using TAS have a maximum time of 5.81 hours compared to trucks using TAS which have a maximum time of 5.15 hours.

Figures 3. Average Queue Length for Each Scenario

The average queue length shows a very significant decrease, comparing the base case scenario and alternative scenarios. In Figures 3, the longest average queue is from Friday to Sunday where the volume
of trucks coming is much larger than other days. The decrease in queue length occurs from Friday to Sunday. Each alternative scenario can reduce the queue length on these three days significantly. Scenario 1 can reduce the average queue length for the three days by 54%, from 162 trucks to 75 trucks and Scenario 2 can reduce the average queue length by 47%. Furthermore, Scenario 3 and 4 can reduce the average queue length for the three days by 86% and 88%. Scenario 5 can reduce the average queue length for the three days by 97% compared to the base case scenario (the average queue length of 162 trucks) to only five trucks on average queue length at Terminal 3 Ocean-going.

Scenario 5 shows that the implementation of TAS can reduce and almost eliminate all the queues at Terminal 3 Ocean-going, from 162 trucks in the base case scenario to 5 trucks when using TAS with 100% utilization when all container trucks are entering the Ocean-going terminal.

6. Conclusion
This study reveals specific problems at Terminal 3 Ocean-going in every planning area. The biggest challenge faced by the operator is a limited yard area for temporary container storage and congestion at the terminal entrance gate due to volume increase every week.

The landside operation for container trucks includes (1) document transactions at both customs and terminal arrival gate, (2) the container handling process, and (3) document transactions at customs and terminal departure gate. Problems arise when there is a surge volume of the truck during peak days leading to congestion at Terminal 3 Ocean-going entrance, i.e., the customs gate. During peak days, each truck needs 11 hours to complete its activity at Terminal 3 Ocean-going with around 10 hours spent in the queue line.

This study proffers the truck appointment system (TAS) as a viable solution for Terminal 3 Ocean-going and lanes segmentation. Based on the results of Scenario 1 through 5, we conclude that a truck appointment system and lanes segmentation can reduce congestion at the terminal significantly even if the utilization is just 15% in Scenario 1. In Scenario 2 and 4, we show scenarios to use an additional terminal gate as incentives for trucks using TAS based on the difference in improvement between trucks using TAS and regular trucks. Furthermore, this study demonstrates the full utilization of TAS, simulated in Scenario 5, reduces the total time in the system significantly with 83.2% decrease from the base case scenario.

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