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## Analysis Queuing and Cycle Times of Barge in Coal Shipment at XYZ Port Using Arena Simulation

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### ABSTRACT

PT XYZ's coal port faces operational challenges with barge queuing and cycle times, threatening efficiency as production scales from 46 million tons (2024) to 54 million tons (2026). Addressing these bottlenecks is critical to maintaining cost-effective operations. This study analyzes the root causes and proposes targeted improvements to optimize port performance. This research aims to identify the factors that affect barge cycle times, determine which factors are the biggest contributors to high queues and cycle times, and to establish strategic steps that companies need to take. The method is carried out through a mixed method, using Arena Simulation Software to conduct modelling, identify obstacles, and determine the strategies to be implemented. Improvements were made to the barge docking process through the implementation of strict SOPs, optimizing port capacity and adding facilities, shortening the process of sending documents by using email and social media, and reducing sailing time by positioning vessels closer to land. By doing this, the output results from modelling in the Simulation Arena showed a reduction in average queue time by 75%, cycle times decreased by 33%, and output increased by 10.53%. Production volume increased by 330,000 tons/month, with potential additional revenue of \$16,170,000.

Keywords: Barge; Port; Queue; Cycle Times; Arena Simulation

### INTRODUCTION

The operation of coal ports such as Port Bunati plays a pivotal role in the efficiency of coal supply chains, particularly for companies like PT XYZ whose core business relies heavily on uninterrupted logistics (Moloto, 2020; Shitu, 2021). Any disruption in port activities, including delays in barge loading or vessel scheduling, can trigger a cascading effect throughout the supply chain, resulting in inventory congestion at mining sites and a failure to meet production targets (Rajendra Rao et al., 2024). Research emphasizes that port infrastructure risks and stakeholder misalignment are major contributors to logistical failures in coal exports (Botha et al., 2019). To counteract these risks, building supply chain resilience through collaborative frameworks and operational contingency planning has proven effective (Sinaga, Simatupang, & Basri, 2024). Moreover, predictive models for port operation optimization help mitigate delays and improve throughput performance (Zeng et al., 2023). Studies in China's coal-power logistics also highlight the importance of diversifying transportation modes and routes to ensure stability during disruptions (Yu et al., 2023). External factors such as extreme weather events can prolong port downtimes, with average disruption durations reaching up to six days and affecting trade flow significantly (Verschuur, Kok, & Hall, 2020). Hence, resilient port management is not only critical for business continuity but also for sustaining coal production and timely delivery to customers (Verschuur et al., 2023).

As PT XYZ's coal production rises from **46 million tons in 2024**, to **51 million in 2025**, then **54 million in 2026**, continuing until mine closure in **2036**, the port's operational complexity intensifies, and so do common issues like **high barge queues** and **lengthy cycle times**. Without robust capacity planning and queue management, these conditions degrade throughput efficiency and elevate demurrage and delay costs (Sier et al., 2014). Increasing throughput volumes strain existing berth and loader infrastructure, underscoring the importance of predictive simulation and priority sequencing in port operations (Rajendra Rao et al., 2024). Empirical studies from Indonesian coal ports reveal that prolonged waiting and discharge times due to vessel and barge density significantly hinder productivity and contribute to coal cargo loss (Ricardianto et al., 2023). Research from dry bulk terminals emphasizes the benefits of integrated scheduling — coordinating unloading, yard, and transport planning — to reduce cycle time and optimize berth utilization (Li et al., 2025). Queuing theory models in port contexts further show that mismatch between service capacity and rising demand leads to exponential increases in waiting time (Roy, 2022). Global analyses suggest that port resilience frameworks—including buffer capacity, additional facilities, and stakeholder coordination—are essential to handle surge volumes and alleviate queue effects (UNCTAD, 2024). Altogether, as volumes grow year-on-year, without strategic port management, high queuing, longer cycle times, and capacity shortages will escalate, compromising PT XYZ's ability to meet production targets. Previous studies have explored similar challenges in port operations. For instance, Kleinrock (1975) and Gross & Harris (2008) investigated queuing theory applications in logistics, highlighting the significance of reducing waiting times to improve efficiency. However, these studies generally focused on broad logistics systems without specific attention to coal port operations. Banks et al. (2005) employed discrete-event simulation to model port activities but did not analyze detailed components of cycle time such as berthing, document processing, and sailing times, which are critical in coal shipment contexts. This research addresses that gap by utilizing Arena Simulation to model and analyze these specific factors, providing targeted strategies tailored for PT XYZ's port.

The objectives of this research are: to identify the factors affecting the cycle time process and determine which processes contribute most to cycle times; to uncover the causes behind high and variable cycle times and queues; and to propose improvement strategies for the company to implement.

One of the key processes for mining companies, especially coal companies, is product delivery to customers. These companies often rely on ports for shipment, whether on their own or third-party ports serving public interests. Large-scale producers typically own their own ports to facilitate production activities, as third-party ports require sharing facilities with other companies and incur higher costs.

Port performance is commonly assessed through metrics such as berth occupancy, turnaround time, vessel waiting time, and throughput. Berth Occupancy Ratio (BOR) is calculated as the total time the berth is occupied divided by the total available time. Turnaround time refers to the period a vessel spends from berthing to leaving the jetty. Waiting time is the duration vessels wait before moving to a berth to load. Throughput measures the volume or number of vessels loaded until the process completes. Turnaround and waiting times constitute part of the vessel's cycle time.

At *XYZ Port*, cycle time is a critical Key Performance Indicator (KPI) to evaluate port performance, specifically for transshipment barges following a fixed route between the port and mother vessels. By definition, cycle time includes the total duration of a process from start to finish, encompassing both processing and waiting times.

The cycle time for one barge can be expressed as:

$$\text{Cycle time} = \text{Process time} + \text{Waiting/Queue time} + \text{Transport/Move time}$$

Waiting time is defined as the interval from the submission of the ship mooring application until the vessel moves to the jetty for berthing. According to the Decree of the Director General of Sea Transportation, waiting time is the duration from the ship's arrival time to the start time of its movement towards the berth. Thus:

$$\text{Waiting Time} = \text{Berthing Movement Start Time} - \text{Arrival Time}$$

Waiting time causes vessel queues, which directly impact operational efficiency. To address this issue, *Arena Simulation Software* is applied as a solution. This simulation tool can model various real-world systems such as logistics, transportation, healthcare, and manufacturing. *Arena Simulation* is among the most popular and widely used simulation software across diverse fields, enabling effective analysis and optimization of port operations.

## RESEARCH METHOD

This research adopted a mixed-method approach, integrating qualitative and quantitative techniques to analyze barge queuing and cycle times at *PT XYZ* Port. The qualitative phase involved examining operational logs, SOP documents, and conducting interviews with port personnel to identify key bottlenecks such as berthing delays and document processing inefficiencies. Quantitative data, including historical cycle times from January to March 2024, were collected to measure waiting times at jetties, service durations, and sailing times. Tools like Pareto and fishbone diagrams were used to prioritize critical factors, revealing that 80% of delays stemmed from berthing and queuing processes.

To model and analyze these issues, a discrete-event simulation (DES) was developed using *Arena Simulation Software*. The model included entities like barges, with arrival rates fitted to a  $\beta$ -distribution, and processes such as berthing, loading, and document processing, modeled using Weibull, Erlang, and uniform distributions. Resources such as jetties and tugboats were incorporated, with capacities adjusted to simulate improvement scenarios. Model validation was performed through face validity checks with port operators and statistical verification, achieving a MAPE of 7.96%. Ten replications produced stable results with a 95% confidence level and a margin of error of 6.748.

Four improvement strategies were simulated: optimizing berthing by enforcing strict SOPs and adding tugboats, expanding jetty capacity, digitizing document processes, and repositioning anchorage vessels closer to the port. These strategies collectively reduced queue times by 75%, cycle times by 33%, and increased barge throughput by 10.53%. The mixed-method design contextualized quantitative findings with qualitative insights, while *Arena's* dynamic modeling effectively captured the complexities of port operations. This approach both identified inefficiencies and provided actionable solutions, demonstrating its practicality and reproducibility for similar logistical challenges.

## RESULT AND DISCUSSION

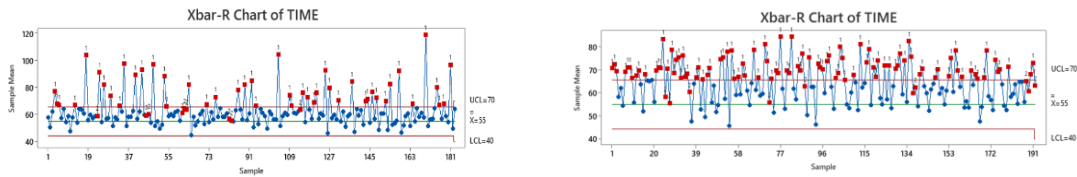
### Analysis

#### 1. Cycle Times

Cycle times and queues are problems encountered in operational activities at the Port. The high number of cycle times and queues shows that the port's performance is less than optimal and less productive.

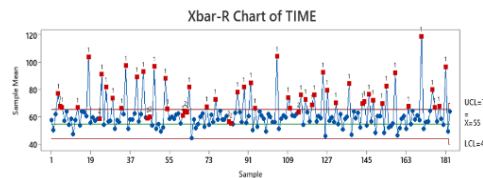
Data on cycle times for the three-month period from January to March 2024 at PT XYZ Port, shows that the number of cycle times is very high and varies.

The Xbar-R chart of time for cycle times is shown as below



**Figure 1. Barges Cycle Times period Jan – Feb**

Source: PT XYZ historical data (2024)

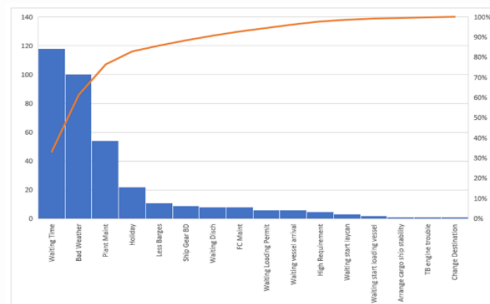


**Figure 2. Barges Cycle Times period March**

Source: Arena simulation analysis, PT XYZ (2024)

From the graph above, it shows that there is a barge Cycle Time shows fluctuating figures, some even more than 100 hours . So it is necessary to detail which part has an influence or is the biggest factor contributing to the increase in barge cycle time.

Using pareto diagrams are obtained as follows

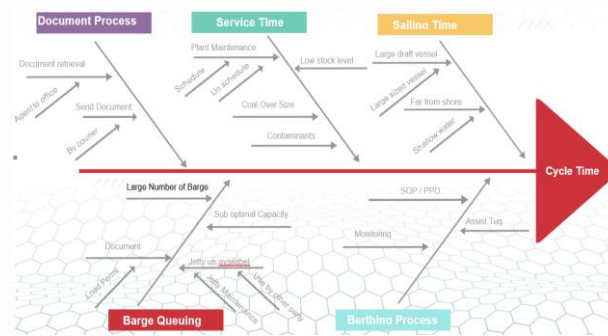


**Fig. 3. Pareto**

Source: Operational data analysis, PT XYZ (Jan-Mar 2024)

From historical data from January to March 2024, the queue of barges waiting for the loading process at the port is the factor that has the largest contribution from cycle times. Adverse weather factors were not taken into account in this study.

Below is a fishbone diagram that shows what factors are causing high cycle times.



**Figure 4. Fishbone Diagram**  
Source: Field identification, PT XYZ (2024)

The following are the basic causes of high cycle times and queues:

1. **Berthing Time**  
Factors that cause the high berthing time number include the implementation of less strict SOPs, lack of monitoring, and lack of tug assistance for entering and exiting barges at the jetty.
2. **Queueing Time**  
The causes of the high queueing time are influenced by the large number of barges queuing, the lack of optimal port capacity operation, documents for vessel loading permits, jetties that are not available due to dredging activities, fender repairs, maintenance work at ship loaders while for third-party ports due to maintenance or used by other parties,
3. **Service Time**  
Service time is the time required by the barge which is calculated from the start of leaning on the jetty (in position), carrying out the process of loading coal to the barge until it is completed until the barge casts off from the jetty. Service time is affected by the speed of loading coal to the barge until it is completed. Factors that affect the speed of loading to the barge include plant maintenance, the amount of coal stock or supply cargo from hauling is less, so that the capacity cannot operate optimally,
4. **Sailing Time**  
Sailing time is influenced by the proximity of the port position of the loading port to the anchorage vessel. The closer the anchorage vessel, the sailing time can be reduced, and vice versa, the farther the anchorage vessel, the longer the sailing time. However, the thing that needs to be considered is that the position has a depth that is still safe for the vessel to anchor,
5. **Processing Document**  
Document retrieval and distribution is the cause of the long document process, this is due to the distance between the agent and the shipper.

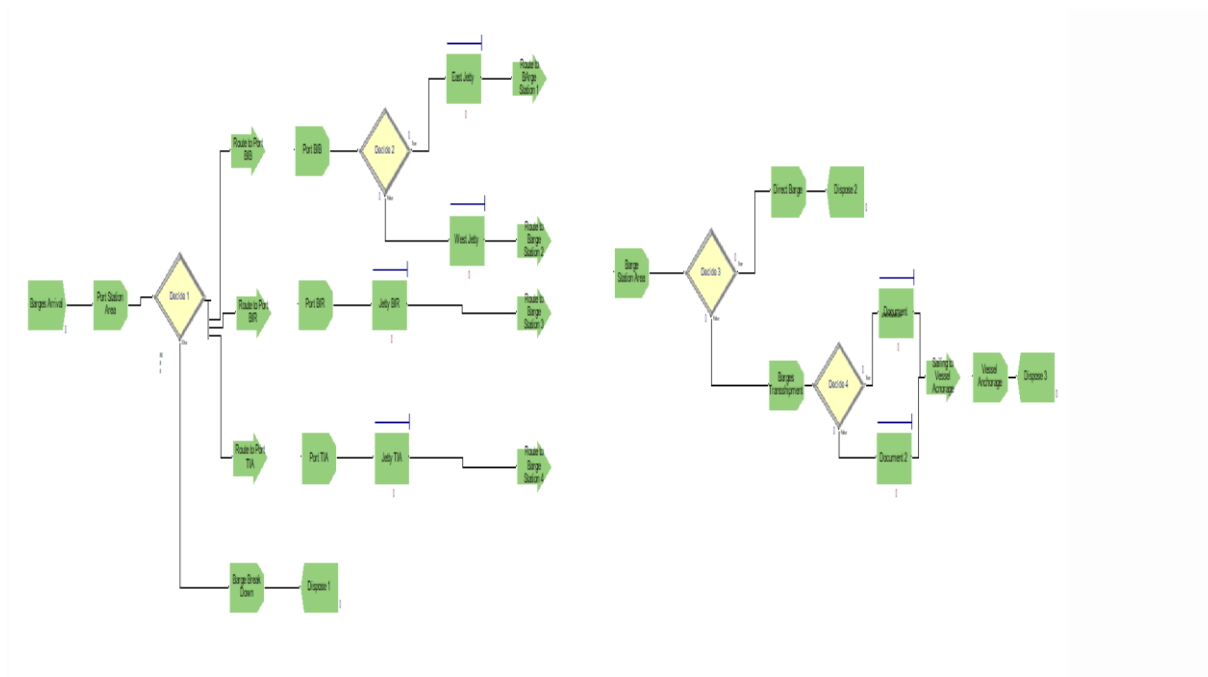
## 2. Model

Barges that arrive at the Port area will then be served by 4 servers, in this case 2 servers from the Port of PT XYZ which has 2 jetties, namely jetty east and jetty west. Meanwhile, the other 2 servers are using third-party port facilities, namely PT A Port and PT B Port.

In its use, the port itself is the port of PT XYZ is the main priority for operational activities. For the other 2 ports, they are used at certain times as support so that operational activities can run smoothly. So that the priorities of these two ports are from low to medium

Because it functions as a support and the main priority is to use its own port, the use of the port is limited. In terms of budget, the maximum is 25% of production or shipping, but in

daily practice the number is much smaller. Along with and in line with the management policy that the use of third-party ports is minimized as little as possible. The modelling is made according to the real processes that occur in the field, here is the simulation model in the Arena Simulation:



**Figure 5. Simulation model by using Arena**

Source: Author's modeling using Arena Simulation Software (2024)

a. Create module

The Arena simulation starts from the Create module, in this model the create module consists of one entity, namely barges. The following is the time between arrival and function of barges.

**Table 1. Create module**

Name	Entity Type	Expression	Function
Barges Arrival	Barges	$-0.001 + 8 * \text{BETA}(0.722, 3.81)$	It creates the barges arrival at port station area

Source: Author's Arena model configuration (2024)

b. Process module

From the Simulation Arena model, there are several process modules. Here is the process module :

**Table 2. List of process**

Name	Action	Delay Type	Expression
East Jetty	Seize Delay Release	Expression	$2 + \text{WEIB}(0.874, 1.12)$
West Jetty	Seize Delay Release	Expression	$1 + \text{ERLA}(0.183, 5)$
Jetty PT A	Seize Delay Release	Expression	$\text{UNIF}(8, 19)$
Jetty PT B	Seize Delay Release	Expression	$4 + 21 * \text{BETA}(0.607, 0.68)$
Document	Seize Delay Release	Normal	1.5, 2
Document 2	Seize Delay Release	Normal	1.5, 2

Source: Arena simulation parameters, PT XYZ (2024)

c. Decide module

The table below is an explanation of the decide module :

**Table 3. List of Decide module**

<b>Name</b>	<b>Type</b>	<b>If/Add</b>	<b>Expression</b>
Decide 1	N-way by chance	85, 8, 6, 1	N/A
Decide 2	2-way by condition	Expression	East Jetty.WIP <= West Jetty.WIP
Decide 3	2-way by chance	12, 88	N/A
Decide 4	2-way by chance	55, 45	N/A

Source: Author's simulation design (2024)

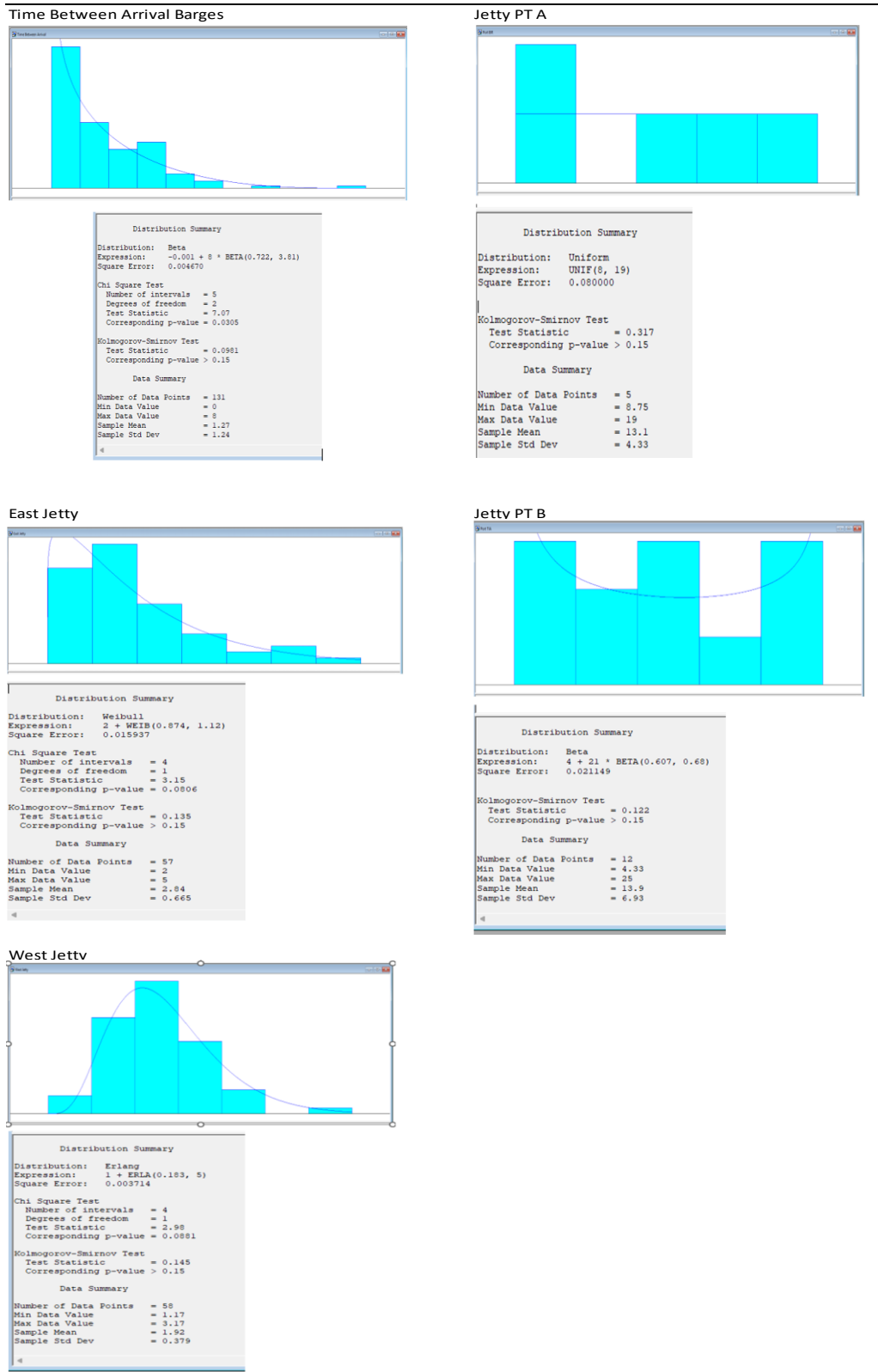
d. Dispose module

In this model there are 3 dispose modules, dispose module 1 when the barges are removed due to breakdown, the 2nd dispose module is for direct barges when cast off from the jetty then it is declared completed from the system and the third dispose module is for transshipment barges that have arrived at the anchorage vessel.

e. Data collection and distribution fitting

Data collection was carried out in the period of 3 - 9 January 2024. For distribution fittings by using the input Analyzer tool in software Arena Simulation.

Here is the table distribution fitting :



**Figure 6. Distribution fitting of collected data**  
 Source: Arena Input Analyzer results (2024)

f. Number of replication

For each model to be able to get close to the real system, replication needs to be done. Here is the calculation for the replication required by calculating the output of the number of barges.

	Ft Data Model
	1 96
	2 118
	3 105
	4 121
	5 98
	6 108
	7 108
	8 111
	9 91
	10 103
Average	105,9
Standart Dev	9,433

With a value :

$$n : 10$$

$$df = n-1 : 10 - 1 = 9$$

$$\text{Confidence level} : 95\%$$

$$\alpha : 1 - 0,95 = 0,05$$

Calculate margin of error (e)

$$e = \frac{(t_{\alpha/2, n-1}) \times S \text{ dev}}{\sqrt{n}}$$

from table t-distribution then the value  $t_{\alpha/2, n-1} = 2,262$

$$\begin{aligned} \text{Then : } e &= \frac{2,262 \times 9,433}{\sqrt{10}} \\ &= \frac{21,337}{3,162} \\ &= 6,748 \end{aligned}$$

Calculate the minimum number of replications (n)

$$\begin{aligned} n &= \left( \frac{(t_{\alpha/2, n-1}) \times S \text{ dev}}{e} \right)^2 \\ &= \left( \frac{2,262 \times 9,433}{6,748} \right)^2 \\ &= \left( \frac{21,337}{6,748} \right)^2 \end{aligned}$$

$$= (3,162)^2$$

$$= 9,997 \approx 10$$

So from the calculations made, the minimum number of replications required is 10.

g. Verification and validation of the model

When the system model in the Arena Simulation software has been created, the model is verified. The purpose of this verification is to find out if there are errors in the system model. Thus, it can also be known whether the system model made is close to the real system or not. Verification is carried out on the Arena simulation software by :

- Click the menu home
- Click Check model
- A Box appears that contains “No Error or Warning in Model”

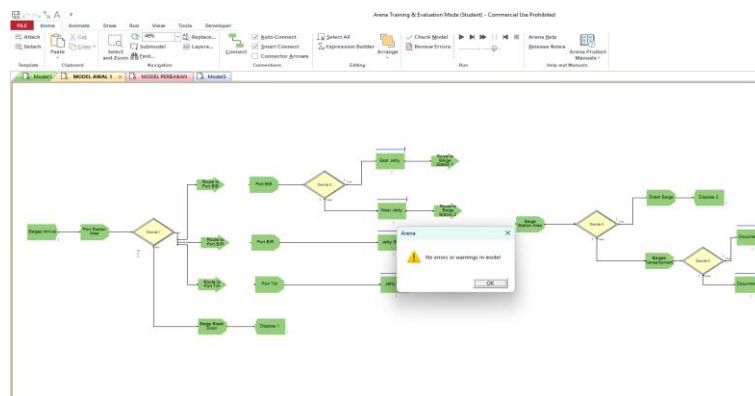


Figure 7. Model verification

To find out the validation level between the system model and the real system, the MAPE (Mean Absolute Percentage Error) formula is used with the formula :

$$M = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right|$$

	Ft	At	At - Ft	At-Ft / At	((At-Ft)/At)*100%
	Data Model	Data Histories	Difference		
1	96	110	14	0.1273	12.73%
2	118	113	5	0.0442	4.42%
3	105	91	14	0.1538	15.38%
4	121	102	19	0.1863	18.63%
5	98	107	9	0.0841	8.41%
6	108	115	7	0.0609	6.09%
7	108	118	10	0.0847	8.47%
8	111	111	0	0.0000	0.00%
9	91	91	0	0.0000	0.00%
10	103	109	6	0.0550	5.50%

Total	79.64%
MAPE	7.964%

From the calculation table above, the MAPE figure is 7,964 %, so the system model can be accepted and considered valid.

h. Analysis of the existing model

For the parameters measured are the wait time at each jetty, incoming barges and outgoing barges. Barges out are one of the parameters measured in accordance with management instructions related to production targets.

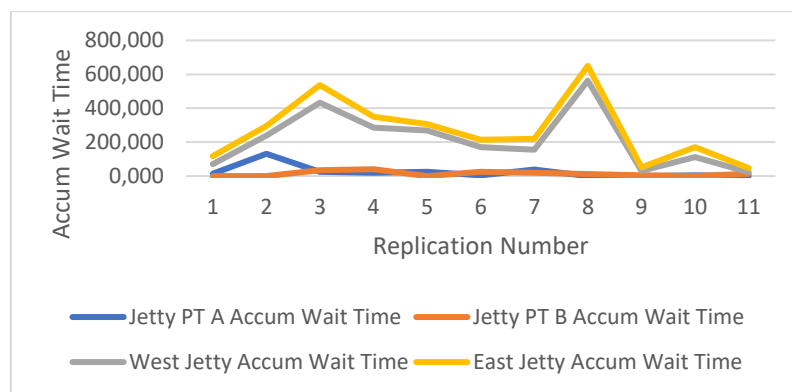
From the running initial model, the following outputs are obtained

**Table 4. Average wait time and barge number in-out**

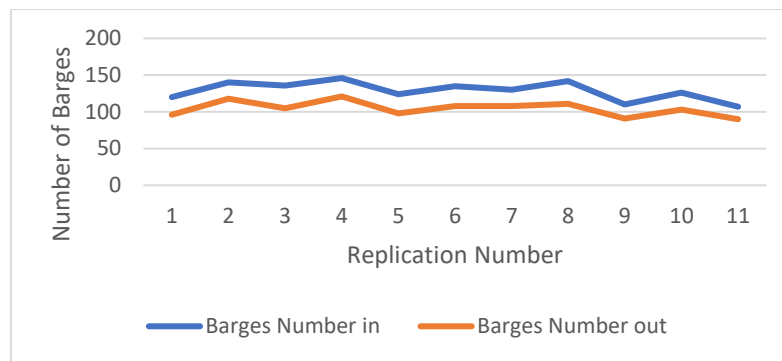
Rep	1	2	3	4	5	6	7	8	9	10	11	Average
Jetty PT A Accum Wait Time	13.212	131.440	25.308	18.936	24.637	3.536	39.142	0.000	0.000	4.684	0.000	23.718
Jetty PT B Accum Wait Time	0.000	0.000	34.067	40.242	0.000	24.909	19.065	11.864	4.628	0.000	14.351	13.557
West Jetty Accum Wait Time	69.927	239.000	432.270	285.170	268.180	170.420	156.370	562.410	30.723	112.090	23.024	213.599
East Jetty Accum Wait Time	117.310	294.530	537.360	350.670	305.930	213.350	220.100	649.700	52.299	170.020	47.371	268.967
Barges Number in	120	140	136	146	124	135	130	142	110	126	107	128.727
Barges Number out	96	118	105	121	98	108	108	111	91	103	90	104.455

Source: Baseline simulation output (2024)

From the table above, it shows that the waiting time, especially at PT XYZ Port, East Jetty and West Jetty is very high.



**Figure 7. Accum wait time at each jetty of the existing model**  
Source: Author's initial simulation results (2024)



**Figure 8. Barge number in – Barge number out of the existing model**  
 Source: Arena simulation data (2024)

Improvement model

**Reduce Time Route To Port XYZ**

From the PPO, it is still possible to make improvements to reduce the berthing process time, even though with this PPO it has reduced the average time of barges to maneuvering for alongside from 1.5 to 1 hour.

The existing PPO has not changed, but it is emphasized again in its implementation in the field and monitored closely, so that operations can run more efficiently.

The first thing that can be improved in the PPO that the information or backup order is carried out early. Earlier info will make you prepare earlier and be able to move earlier.

In order for this to be done, a barging line up was made by the PT XYZ team, in this case the Onshore Team Leader. Barging Line Up, is an arrangement of barges arranged in order consisting of the name of the tug boat, the destination and the name of the surveyor. Especially for long towing barges, the amount of coal that must be loaded is also listed, to avoid the occurrence of death freight or lack of coal cargo in the barge, which will have an impact on claims and penalties from the buyer.

With the barging line up that has been prepared, it will be immediately distributed to all related parties, both internally and externally such as jetty, barging partners, agencies, and port contractors. Thus, information to the Tug Boat crew can be done without having to wait for the barge that is berthing and loading on the jetty to have finished carrying out activities. Information about the barging line up has been shared in the WA group in the morning on shift 1, which is used as a reference for barge mooring. The barging line up will be updated if there are any changes.

When it is close to the turn of the Tug Boat / Barge to carry out the berthing process, the jetty will reconfirm to the Tug Boat for the progress of the preparation. This was done 3 hours before the barge's turn to move, considering that this preparation process takes quite a long time from starting from removing the rope from the Mooring Buoy or heaving up anchor, transferring the crew from the Tug Boat to the barge, preparing the heaving line (rope used to help pull the mooring line from the jetty to the barge). Once all are ready then the Tug Boat / Barge will move closer to the jetty as per the instructions to alongside at the west jetty or the east jetty.

When the barge on the jetty is approaching the completion process, the replacement barge is ready in front of the jetty to carry out the leaning process to replace the previous position of the barge.

The second thing that can be improved is the Assist Tug, which is a Tug Boat that helps in the process of moaning and exiting the barge from the jetty. Assist Tug must be present in every entry and exit operation of the barge.

With the increasingly crowded operation at the jetty, the availability of Assist Tug is absolutely necessary. So that it does not cause delays in operations, especially in the process of entering and exiting barges. The Assist Tug, which initially amounted to 1 unit, needs to be increased to 2 units. With the number of 2 assist tugs, the barge that will be berthed no longer needs to wait for the tug assist who is helping the barge exit process from the jetty. With 2 Tug assists, 1 Tug assist helps the barge exit process and 1 tug assist is already on the replacement barge.

Thus, the barge that will be berthed can immediately move into the port area and approach the jetty. The movement of the Assist Tug from helping the barge outside the jetty to being in position on the replacement barge takes about 20 minutes.

By doing the above, the maneuvering process for alongside at the jetty becomes smoother and there is no delay to wait so that the change of barge becomes faster. Thus, it will reduce the time to be shorter and can reduce the berthing time which was previously average at 60 minutes reduced by about 30% to 40 minutes.

For third-party ports, each has its own authority, rules and assistance for the berthing process. So from the side, only BIB gives them information about the name of the Tug Boat/Barge, destination, surveyor and the position of the Tug Boat/barge that is ready to be berthed.

### **Improvement Services Time**

Service time is service time at the jetty is one of the contributors to the cycle time process, which is calculated from the start of the barge berthing on the jetty, to the last line or cast off of the jetty. There are 3 phases of the process in the jetty, namely the reading of the initial draft, and the final draft and loading process. The initial and final draft readings lasted a short time of about 10 minutes, then the calculation itself was done on the jetty.

The process of loading to the barge is very important in the cycle time process chain, because it will cause a domino effect on other processes. The fast loading process will reduce the process of service time, in addition to the faster the loading of Coal on the barge, the empty barge queue waiting to load will automatically be reduced. Thus the barge queue time is reduced. And resulting in reduced cycle times.

The installed capacity for BLC at Port PT XYZ is 8,400 MTPH. However, in reality, the loading process is still below the installed capacity, on average, half of the BLC capacity, which is around 4,000 – 4,200 tons/hours. This is due to several things, where the feeding capacity cannot keep up with the capacity of the BLC even though the feeding capacity is calculated if it is operated slightly above the capacity of the BLC.

In order for capacity optimization to run according to the installed capacity, several things need to be done, that is:

1. Reducing the delay of shifting barges, in the process of loading coal to the barge because the position of the ship loader is fixed so what is shifted is the barge. In the barge shifting process, the conveyor continues to operate and continues to load on the barge. In one loading process to the barge requires 2 times shifting, one shifting backward and one shifting forward,
2. Reducing unscheduled maintenance, one of the things that causes non-optimal capacity is when there is scheduled maintenance, because out of 2 BLC lines, only 1 is operating,
3. Scheduled Maintenance, communicated and coordinated with all parties taking into account the level of urgency of operation and maintenance. The maintenance schedule is shared with the operation team, and from the operation will provide feedback in the form of when maintenance should be carried out by considering less congested operating conditions,

4. The setting of plant equipment is adjusted to the installed capacity and is not reduced, because some facilities are set far below the installed capacity, so they cannot operate optimally,
5. Facilities at the Port can be operated simultaneously, no one is on standby,
6. The addition of new facilities so that the feeding capacity is even greater than the capacity of BLC, which can also function as a backup when there is damage or obstacles, so that it does not have a significant effect on the running operation,
7. By taking the above steps, it is hoped that the operation can run optimally according to the installed capacity, from an average of 4,000-4,000 tons per hour, close to the installed capacity of 8,400 tons per hour.

Meanwhile, the third party port also optimizes its capacity. Optimization can be done by maximize utilization all existing facilities at the port, re-arrangement working and rest times, reducing unscheduled maintenance, and operational delays, also if necessary, increasing capacity with minor change.

In the Arena simulation, changes were made in the resources module where previously Capacity was written 1 changed to 2. With optimization, it is hoped that the capacity can increase 2 times according to the installed capacity

### **Document Acceleration**

Then the document is distributed to the agent via email or whatsapp, and the agent will forward the message to Tug Boat by email or whatsapp.

Thus, by using email and social media, cargo documents from the shipper will be received at the Tug Boat on average about 1 hour. So reduce the time by 30 minutes if the agent comes and picks up the physical documents themselves at the shipper's office. So in the simulation arena, the document module Value (mean) changes to "1".

### **Sailing Times**

Sailing time is the time required by the Tug Boat – Barge sailing from the loading port to the anchorage of the Mother Vessel. This travel time is influenced by distance, the farther the distance, the longer it will be, and vice versa, the closer the distance, the faster.

In order for sailing time to be reduced, coordination with several parties is needed, one of which is the vessel agent. A vessel agent is a party that acts as an intermediary or liaison between the Vessel and other parties, one of which is the shipper.

The average anchorage point distance of the Mother Vessel is 14.5 NM, with an average travel time of 8 hours, then the average speed of the Tug Boat is 1.81 NM/hours. In order to reduce the sailing time, the anchorage position becomes closer to the jetty. In order for this to be achieved, the anchorage position of the jetty on average is 12.67 NM.

By setting the vessel's anchorage position at a distance of 12.67 NM, it will reduce the distance from the jetty or from the land so that the barge's travel time becomes shorter. In this position, the reduction in sailing time is 1 hour. Thus, it is hoped that the average travel time can be reduced, from 8 hours to 7 hours.

This figure is obtained from the average speed x expected time, which is  $1.81 \text{ NM/hours} \times 7 \text{ hours} = 12.67 \text{ NM}$ . So in the Arena Simulation software in the Sailing to Vessel Anchorage module in the Route Time section changed to "EXPO(7)".

The following is a table of changes from existing model to improvement model:

**Table 5. Existing – Improvement model**

Name	Action	Delay Type	Existing Model	Improvement Model	Units
Process			Expression	Expression	
Document	Seize Delay Release	Normal	1.5, 2	1, 2	Hours
Document 2	Seize Delay Release	Normal	1.5, 2	1, 2	Hours
Route					
Route to Port PT XYZ					
			EXPO(60)	EXPO(40)	Minutes
Sailing to Vessel Anchorage			EXPO(8)	EXPO(7)	Hour
Resources					
	Type		Capacity		
CP1	Fixed Capacity		1	2	
CP2	Fixed Capacity		1	2	
CP3	Fixed Capacity		1	2	
CP4	Fixed Capacity		1	2	
PT A1	Fixed Capacity		1	2	
PT B1	Fixed Capacity		1	2	

Source: Author's simulation parameter adjustments (2024)

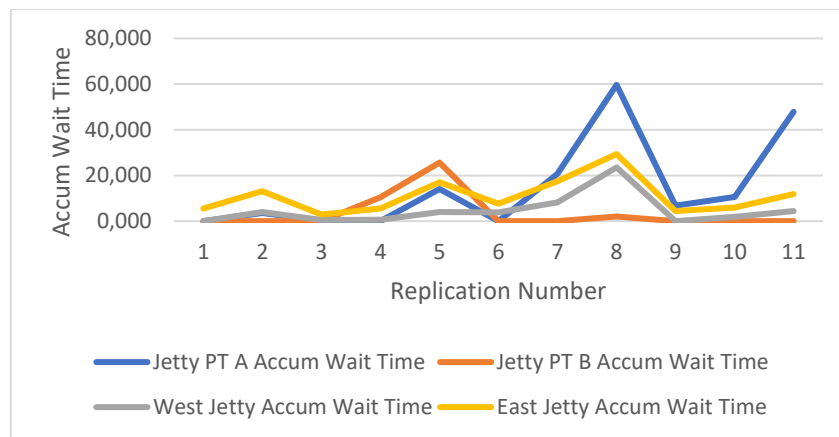
2.10. Result

From the results of the improvements made above, the output produced is as follows

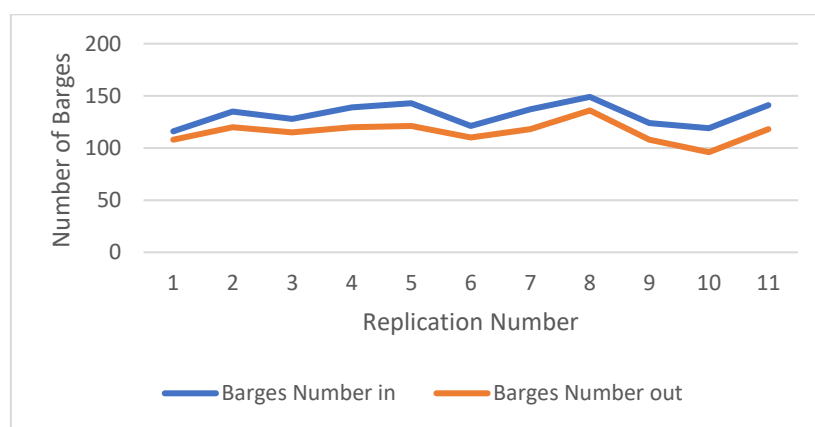
**Table 6. Arena Simulation output model improvement**

Rep	1	2	3	4	5	6	7	8	9	10	11	Average
Jetty PT A Accum Wait												
Time	0.000	3.586	0.379	0.000	14.065	0.000	20.612	59.667	6.735	10.528	47.824	14.854
Jetty PT B Accum Wait												
Time	0.000	0.000	0.000	10.433	25.628	0.000	0.000	2.021	0.000	0.000	0.000	3.462
West Jetty Accum												
Wait Time	0.000	4.038	0.499	0.560	4.029	3.914	8.162	23.525	0.000	1.918	4.470	4.647
East Jetty Accum Wait												
Time	5.539	13.082	2.878	5.526	17.056	7.665	17.500	29.360	4.362	5.943	11.842	10.978
Barges Number in	116	135	128	139	143	121	137	149	124	119	141	132.00
Barges Number out	108	120	115	120	121	110	118	136	108	96	118	115.45

Source: Enhanced simulation results (2024)



**Fig. 9. Accum wait time at each jetty of the improvement model**



**Fig. 10. Barge number in – Barge number out of the improvement model**

Here is a comparison table between the Existing model and the Improve model

**Table 7. Existing vs improve model**

Identifier	Existing Model	Improve Model	Units	
	Average	Average		
Jetty PT A Accum Wait Time	23.718	14.854	Hours	-37.37%
Jetty PT B Accum Wait Time	13.557	3.462	Hours	-74.46%
West Jetty Accum Wait Time	213.600	4.647	Hours	-97.82%
East Jetty Accum Wait Time	268.970	10.977	Hours	-95.92%
Barges Number in	128.720	132.000	Sets	2.55%
Barges NUMBER Out	104.450	115.450	Sets	10.53%

Source: Author's comparative analysis (2024)

From the table above, it can be concluded that:

- There was a reduction in queue time at Port PT A by 37.37 %
- There was a reduction in queue time at Port PT B by 74.46%
- There was a reduction in queue time at the West Jetty by 97.82%
- There was a reduction in queues at the East jetty by 95.92%
- There is an inbound barge increase of 2.55%, or 3 sets
- There was an increase in barge output by 10.53%. or 11 sets

Waiting times for barge queues are reduced by about 75% on average and Cycle time is reduced about 33%. With an additional output of 11 sets of barges for a week, the additional volume produced is 82,500 tons per week or 330,000 tons per month.

### 3. Cost Benefit Analysis

In order for the improvement process to be carried out properly, some additional man power is needed in several positions. In addition to the cost for wages, there are costs for training needed for the up-grade competency of new employees

With the increase in production volume, there are operational costs incurred. And on the other hand, there is revenue from the addition of production volume.

The following is the calculation of the cost improvement that arises and the revenue generated

**Table 8. Table Cost - Revenue**

	\$ / Month
Additional Man Power Cost	8,818.19
Operational Cost	5,645,000.00
Royalty	2,182,950.00
Revenue	16,170,000.00
Profit	8,333,231.81

Source: PT XYZ financial data (2024)

Assumption : \$ 1 = Rp 16,500

Additional production volume is for transshipment for export purposes

The total overall cost is  $\text{Additional Man Power Cost} + \text{Operational Cost} + \text{Royalty} = \$8,818.19 + \$5,645,000 + 2,182,950 = \$ 7,836,768.18$

The revenue generated was \$16,170,000.

Thus the resulting profit is  $\$16,170,000 - \$7,836,768.18 = \$ 8,333,231.81$

With the additional profit generated is quite large is \$ 8,333,231.81 which can be used for both internal and external benefits of the company.

### CONCLUSION

The primary factors contributing to high cycle times at PT XYZ Port are prolonged barge waiting times from arrival to movement initiation for docking, sailing time to the mother vessel anchorage, docking procedures, and document distribution delays. Key underlying causes include inadequate implementation and monitoring of SOP/PPO for docking, inefficient use and alternating allocation of tugboats, suboptimal utilization of port facilities, high barge volume, and unscheduled plant maintenance. Additionally, the anchorage vessel's distance and lengthy document processing further exacerbate delays. Simulation using Arena Software demonstrated that targeted improvements could reduce queue times by 75%, cycle times by 33%, and increase barge throughput by 10.53%, resulting in an additional production of 330,000 tons per month and potential monthly profit exceeding \$8.3 million after cost savings. Future research could explore real-time monitoring and adaptive scheduling systems to further optimize docking operations and integrate predictive maintenance to minimize unscheduled downtime.

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