CRSUSF
Critical Issue of Sustainable Future
CRSUSF 2(1): 66–79
ISSN 3048-1759

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Optimizing tugboat fleet efficiency in port operations using discrete-event simulation modeling

Obay Haqi Rifan Arief[1,*], Ratih Dyah Kusumastuti[2]
[1] *Department of Management, Faculty of Economics and Business, Universitas Indonesia, Depok, West Java, 16424, Indonesia.*
*Correspondence: haqiobay3@gmail.com

Received Date: January 3, 2025 Revised Date: February 28, 2025 Accepted Date: February 28, 2025

ABSTRACT

Background: In Indonesia, marine logistics is considered a priority sector because 40% of international trade passes through the country, with 90% of it utilizing sea transportation. Therefore, this research aims to determine the optimal number of tugboat fleets operating at Tanjung Priok Port by evaluating the average overall time and waiting time for pilotage activities and towage services. **Methods**: This study used secondary data sourced from the 2019 Daily Report on Ship Movements by PT. P (Regional 2). A discrete-event simulation method was applied using Arena Simulation software, incorporating a scenario where one chartered tugboat unit was reduced. **Findings:** The results showed that PT. P already provides effective pilotage and towage services. Furthermore, reducing one 1240DK tugboat unit had no significant impact on the company's initial operational performance. **Conclusion:** PT. P's current tugboat fleet is sufficient to maintain service efficiency, even with the reduction of one unit. **Novelty/Originality of this article:** This study offers insight into optimizing tugboat operations through simulation modeling, presenting an approach that has not been extensively explored in Indonesian port logistics.

KEYWORDS: arena simulation; discrete-event simulation; pilotage and towage services; sea transportation; tugboat fleet.

1. Introduction

The logistics industry is a series of systems that manage the handling, movement, and storage of goods, starting from the beginning of production until the goods are received by consumers. Logistics plays an essential role and consists of a series of interrelated activities that are carried out gradually with the aim of managing and maintaining goods within an industry (Suntoro, 2020). In the global logistics industry, its development has experienced significant growth, as logistics has become an important part of economic business systems and global economic activities. Logistics activities can accelerate economic growth and productivity. A high level of logistics performance is crucial for national and global economic profitability and efficiency (Brewer & Hensher, 2001). In Indonesia, logistics serves as one of the pillars supporting the country's economic recovery. This is because the logistics sector acts as both the driving force and the backbone for other sectors to continue moving forward. According to data from Statistics Indonesia, the value of Indonesia's exports increased by 49.7 percent in November 2021 compared to November 2020. Imports also rose by 52.62 percent from the previous year (BPS, 2021). These data indicate that Indonesia has entered a period of rapid economic recovery. This condition is strongly

Cite This Article:
Arief, O. H. R., & Kusumastuti, R. D. (2025). Optimizing tugboat fleet efficiency in port operations using discrete-event simulation modeling. *Critical Issue of Sustainable Future, 2*(1), 66-79. https://doi.org/10.61511/crsusf.v2i1.1802

supported by the role of the logistics sector, which accelerates economic activity and highlights the need for Indonesia to enhance its logistics operations to support national economic development.

A positive indication of economic growth must be supported by improved performance in the logistics sector. According to the Chairman of the Supply Chain Indonesia, the port or marine logistics sector should be prioritized because Indonesia is an archipelagic country with more than 17,000 islands spread across vast seas (Azka, 2020). Directorate General of Sea Transportation, this geographical reality makes sea transportation a highly significant component in connecting the islands and supporting Indonesia's economy. In the 2020 World Competitiveness Ranking, Indonesia was ranked 40th out of 63 countries in global competitiveness (Nino, 2020), partly because 40 percent of international trade flows through Indonesia, with 90 percent of it relying on maritime transportation (Anwar, 2020). The importance of sea transport continues to grow, as shown by a 7.23 percent increase in ship traffic during the first quarter of 2021 compared to the previous year (Mimbar Maritim, 2021).

However, since the pandemic began, the number of ship visits in Indonesia has decreased, accompanied by a container shortage due to disrupted shipping schedules, leading to difficulties in securing ship space (Puspa, 2021). According to Maersk, this condition reflects a stable and growing demand for containers, which may trigger a sharp increase in demand once the pandemic eases (Lestari, 2022). The Secretary General of the Indonesian Logistics and Forwarders Association (ALFI) also stated that the national logistics sector is expected to continue growing in 2022 due to promising volume and growth trends (Damayanti, 2022). The types of vessels entering port waters include ferries, cargo ships, tankers, cruise ships, crane ships, naval ships, and research vessels (Sari, 2020).

The explanation mentioned above highlights both the challenges and the substantial economic opportunities for Indonesia to become the world's maritime axis if it can optimize the integrity of its existing sea transportation system (Ministry of Transportation of the Republic of Indonesia, 2018). One way to maximize the economic potential of Indonesia's maritime transportation is by ensuring the efficiency of vessel services at ports. Efficient management of sea transportation will enhance the mobility of resource distribution and thereby accelerate economic circulation and growth in Indonesia. One of the crucial components of maritime transportation efficiency is the port, which serves as the main gateway for a country to participate in global industry and trade (Sari, 2011). Productivity and cost efficiency at ports are vital for economic development. If Indonesia can create a productive and cost-efficient port climate, the competitiveness of Indonesian ports will improve compared to major ports in neighboring countries. Therefore, a concrete strategy that can be taken by regulators, the government, and other related stakeholders to improve the efficiency of vessel services at ports is to develop an integrated transportation system for various maritime transport modes (Jinca et al., 2012).

With regard to maritime transportation, it is inseparable from the port and container terminal sectors, which play a highly significant role in global maritime logistics. In 2018, approximately 17.9 percent of global maritime tonnage was handled by container ports (IMO, 2019). In Indonesia, the busiest port is Tanjung Priok Port, which is also one of the largest ports in Southeast Asia (Izzati, 2021). In general, port operational activities are divided into two main categories as illustrated in Figure 1.2. Landside operations typically include gate, yard, and quay activities. In a literature review by Wei et al. (2020), previous studies have discussed various issues in landside operations such as berth and yard equipment scheduling problems, yard management problems, and terminal gate problems (Guan and Liu, 2009; Angeloudis and Bell, 2010; Cao et al., 2010; Sauri and Martin, 2011; Heilig et al., 2017; Zhang et al., 2019). Meanwhile, seaside operations consist of activities involving berth, channel, and anchorage areas. Several studies have focused on seaside operations including issues related to berth allocation and the utilization of anchorage and vessel routes (Jia et al., 2019; Li & Jia, 2019; Xiang et al., 2017).

This research focuses on Tanjung Priok Port because it has the highest intensity of port service activities in Indonesia. Tanjung Priok is the fifth largest port in Southeast Asia, handling an annual traffic of 7.6 million TEUs (Adrian, 2021), which makes it the largest port in Indonesia, managed by PT. P (Regional 2). One of the essential activities in vessel service operations at Tanjung Priok is tugboat operation. Pilotage and towage are two complementary services in vessel handling, especially since Tanjung Priok is designated as a compulsory pilotage and towage port for ships over 500 gross tons (PM No 57 of 2015). Container ships commonly request tugboat assistance during berthing operations, yet the availability and capability of tugboats to fulfill this demand remain limited. Therefore, optimizing the use of tugboats is necessary to ensure that container vessels are served efficiently and effectively. However, tugboat scheduling problems have not gained as much research interest compared to broader maritime operational studies (Kang et al., 2020).

One critical factor that remains suboptimal in supporting vessel service operations is the availability of tugboat fleets, which are essential to minimize ship waiting times at the port (Dwiki, 2021). The insufficient number of operational tugboats, whether as primary vessels or as backups during breakdowns or routine maintenance, often leads to longer waiting times for vessels requiring pilotage and towage services (Andrianto et al., 2017). Research on tugboat management can generally be categorized into two areas. The first concerns tugboat fleet management, which typically involves decisions on determining the number and types of tugboats to be deployed for daily operations. The second focuses on tugboat scheduling, which aims to produce detailed work schedules to ensure timely and organized tugboat services for incoming and outgoing vessels (Jaikumar & Solomon, 1987).

Based on the explanation above, this study aims to determine the optimal number of tugboat fleets required to meet the demand for towage services at Tanjung Priok Port in order to improve the quality of vessel services at the port. Previous studies have proposed several methods for determining tugboat requirements, including mathematical models and simulation models. Mathematical models commonly used include forecasting and linear programming, which are typically applied to landside operations. However, for seaside operations, there are numerous variables that are difficult to interpret using mathematical models, making simulation models more suitable for replicating real-world conditions (Lee et al., 2021). Therefore, this study employs a discrete-event simulation method using the ARENA software to determine tugboat demand under various configuration scenarios (Zhihua, 2003). The performance indicators used to evaluate tugboat utilization at the port include labor scheduling effectiveness and ship waiting status. The results of this analysis are expected to support operational decision-making for the vessel service division at PT. P (Regional 2), particularly in managing the availability of tugboat fleets.

1.1 Supply chain management

Supply chain, or what is commonly referred to as the supply chain, is a part that consists of all parties directly or indirectly involved in the management to meet customer demand. A supply chain does not solely encompass manufacturers and suppliers; it also includes parties such as transporters, warehouses, retailers, and end-customers (Chopra, 2019). Supply chain management is the integration of key business processes to consumers through suppliers who provide products, services, and information that add value to stakeholders (Lambert & Cooper, 2000).

Overall, the supply chain includes several key entities such as suppliers, manufacturers, distributors, retailers, and consumers, and has primary flows within its interactions, including physical flow and information flow (Chopra, 2019). According to Heizer et al. (2017), supply chain management is an integral part that needs to be maximized in every industrial sector, one of which is the logistics industry related to maritime transportation.

1.2 Logistics in the supply chain

Logistics is a system designed to improve operational efficiency through the integration of all materials, movements, and storage activities (Heizer et al., 2017). According to Suntoro (2020), logistics is a field of knowledge that supports various business processes within a company, such as sales, product demand, inventory storage, goods transfer, and delivery. Logistics is the strategic management process of moving and storing goods from suppliers to the company or to customers, characterized primarily by the integration of various dimensions of strategic transportation and storage activities (Bowersox et al., 2020).

The goal of logistics is to deliver various types of materials in the right quantities and at the specified time, at the most economical cost. Therefore, an effective and efficient logistics design is required (Suntoro, 2020). In general, logistics is closely related to the physical flow of goods, starting from the supply of raw materials, storage, production processes, distribution, retail, and ultimately to the customer. This process has now been enhanced by a supporting function—namely, the flow of information—which has become an integral part of the logistics system to provide updates on the movement of goods (Suntoro, 2020). Therefore, the physical flow of goods in logistics cannot be separated from the vital role of the transportation sector.

1.3 Transportation in the supply chain

Transportation plays an important role in society, facilitating various economic activities for individuals, both directly and indirectly (Bardi et al., 2011). Everyday activities, such as consuming goods, mobility, and other activities, are influenced by transportation. Transportation also acts as a bridge between supply and demand, enabling the movement of individuals from one location to another (Bardi et al., 2011). Transportation refers to the activities involved in moving a product from one location to another, starting when the product moves from the beginning of the supply chain to the customer. Transportation is a crucial component because a product is rarely produced and consumed at the same location (Chopra & Meindl, 2016). In supply chain logistics, transportation usually acts as an intermediary that facilitates the physical flow of goods from the point of origin (shipment) to the destination. Companies that implement logistics transportation perform physical distribution functions aimed at moving goods from one location to another (Coyle et al., 1996).

1.4 Maritime transportation in the supply chain

Maritime transportation in the logistics supply chain, or what is often referred to as the maritime supply chain, is an activity composed of the integration of maritime services and transshipment functions with maritime distribution functions (Frankel, 1999). According to Chryssolouris et al. (2004), the maritime supply chain involves various parties, each with its own role, coordinating to carry out operational and distribution or manufacturing activities, and their importance is considered in the development of the supply chain (Lam, 2011). It can be said that the maritime supply chain is a series of activities related to shipping services, which includes planning, coordination, and control of containers in a complex manner between involved parties, from the point of origin to the destination point (Polatidis et al., 2018). According to Song et al. (2016), the maritime supply chain involves complex interactions between the parties involved and requires effective relationship management.

The maritime supply chain is a service sector with an important system that plays a role in connecting various networks. This is because the maritime supply chain plays a critical role as an intermediary and a mode of transportation that facilitates trade flows between continents and globally (Wong et al., 2011). This refers to Cheng et al. (2015), who explained that maritime supply chain operations contribute about 70% of the value of international trade and 80% of global volume. Global trade is highly dependent on maritime transportation to carry cargo in international export-import trade (Osobajo et al., 2021). Therefore, one of the main gateways in maritime transportation activities is the port.

1.5 Seaport

A port is an area where ships are loaded and/or unloaded, and it is also a place where ships queue or are instructed to wait in a specific water area within that region (Alderton, 2008). According to Government Regulation No. 69 of 2001, a seaport is an area consisting of land and surrounding waters with specific boundaries, designated for government activities and economic activities. It is used as a docking place for ships, where vessels can anchor, passengers can board or disembark, and goods can be loaded or unloaded, equipped with facilities for navigation safety and port-related support activities, as well as a place for intra- and intermodal transportation transfer. Based on Government Regulation No. 69, 2001 ports provide facilities and services for visiting ships, which are divided into two main categories: ship services and cargo handling services. One of the ship services is tugboat services, which involve assisting visiting ships in the docking process at the pier.

1.6 Tugboat operations

According to Ministerial Regulation No. 93 of 2014, a tugboat is a vessel with specific characteristics used for pushing, pulling, towing, escorting, and assisting ships maneuvering in the shipping lane, anchorage area, or port basin, either for docking or undocking at the quay, jetty, trestle, pier, buoy, dolphin, ship, and other mooring facilities. Tugboats are used to ensure the safety of vessel navigation with the following provisions (Ministerial Regulation No. 93, 2014); (1) for ships with a length of 70-150 meters, at least 1 tugboat with a minimum power of 2000 horsepower and a minimum bollard pull of 24 tons is required; (2) for ships with a length of 150-250 meters, at least 2 tugboats with a minimum power of 6000 horsepower and a minimum bollard pull of 65 tons are required; (3) for ships longer than 250 meters, at least 3 tugboats with a minimum power of 11000 horsepower and a minimum bollard pull of 125 tons are required.

Each tugboat is obligated to operate under the following conditions Ministerial Regulation No. 93, 2014; (1) meet seaworthiness requirements; (2) have a bollard pull test certificate (test certificate) from a government-recognized classification society; (3) have an approval certificate for the use of pilotage assistance equipment from the director-general; (4) have valid ship documents in accordance with relevant laws and regulations. Each tugboat used for pilotage services must be manned by at least 9 crew members, with qualifications including a minimum Nautical Officer Class III diploma for the captain and a minimum Technical Officer Class III diploma for the chief engineer, as well as other necessary certifications in accordance with legal requirements.

2. Methods

This research begins by identifying problems related to the increasing number of vessel visits for loading and unloading activities at Tanjung Priok Port. The rising volume of ship arrivals can serve as an indication for the next stage, particularly in assessing the readiness and availability of port services to support vessel operations. This includes both service preparedness and the availability of supporting resources for vessel handling during cargo in and outflow processes. The next focus of identification involves assessing the number of tugboat fleets owned by PT. P (Regional 2), particularly in relation to pilotage and towage services. This study concentrates on towage operations, where tugboats play a significant role in maneuvering vessels within the port area. By conducting this identification, it will be possible to determine whether the current tugboat fleet owned by PT. P (Regional 2) is sufficient and aligned with the operational needs of Tanjung Priok Port. The number of tugboats is closely linked to the efficiency of port operations and the operational costs incurred by the port authority. Data collected during the identification phase will then be categorized based on the variables required for this research and used to construct simulation models using ARENA software.

The subjects of this research are tugboats and the vessels that use port services at Tanjung Priok Port. To analyze these operations, the researcher employs a simulation model system to observe specific conditions and events that reflect the actual situation. Through this method, the study aims to determine the number of tugboats required to operate efficiently at Tanjung Priok Port. Developing an accurate simulation model requires several structured steps to ensure that the model reflects real operational conditions. The following stages outline the process of building a reliable simulation model.

The first stage involves formulating the research problem and planning the study. This stage is important for defining the main objective and formulating clear and specific research questions that will later be modeled in the simulation. In this study, the primary issue is determining the sufficient number of tugboats needed for effective towage services at Tanjung Priok Port. The goal is to design simulation configurations that help identify the most suitable fleet size to meet operational demands and improve service efficiency at the port. The second stage includes collecting the necessary data and formulating the model. Data collection is carried out through observation and interviews with personnel in charge of towage operations at Tanjung Priok Port. In addition, relevant secondary data are gathered to form the basis of the simulation model. These data are used to determine parameters and probability distributions that will guide the structure and behavior of the simulation.

The third stage is the validation of the assumptions used in the simulation model. This stage ensures that the assumptions are appropriate and relevant to the actual conditions by discussing the conceptual model and its components with the port authority at Tanjung Priok. This process helps increase the credibility of the model and ensures that it can provide solutions to real operational challenges. The fourth stage is the construction of the simulation model using ARENA software. The model is built as an abstraction of the real-world system, incorporating the assumptions and detailed descriptions of relationships between variables. Once completed, the model must be verified to ensure it aligns with the assumptions and accurately represents the intended scenarios.

The fifth stage involves conducting pilot runs of the model. This initial execution allows the researcher to test the model's logic and structure. The pilot run helps identify any inconsistencies or issues and ensures the model is valid before full analysis is conducted. Step-by-step development is applied to maintain the integrity of the model during the building process. The final stage is the validation of the simulation model. This stage is essential to confirm that the simulation accurately represents the real system. The validation process may include sensitivity analysis or statistical methods. In this study, a base case scenario is used to describe actual operational conditions, along with three proposed alternative scenarios. These scenarios are designed to find the most efficient solution for determining the number of tugboats required at Tanjung Priok Port. Model validation testing for the base case scenario uses a confidence interval of 95%. The model is considered valid if it falls within the established confidence interval. The next step is to analyze the results using a paired t-test. This validation is also applied to the proposed scenario. If the proposed scenario shows significant differences and the parameters used indicate more efficient results, then the proposed scenario can be deemed superior to the base case scenario

The next step is conducting the simulation experiment. This stage involves determining the simulation characteristics, including the run length, sample size, and warm-up period. In this study, each scenario will be replicated 30 times, with the simulation running for 31 days. One day is designated as the warm-up period, reflecting the total number of working days at Tanjung Priok Port. Each day consists of 24 hours, as port operations run continuously throughout the day. These settings aim to replicate the actual operational cycle and ensure accurate model output. The production run stage follows, during which the simulation is executed to generate results that align with the research objectives. At this stage, the expectation is that the developed model will reflect the research goals and represent the conditions accurately. The simulation output from this stage is used as the basis for further analysis and interpretation.

3. Results and Discussion

3.1 PT. P Ship Service Activities (Regional 2)

In vessel service operations, PT. P (Regional 2) focuses on assisting ship operations when entering and leaving the port area. In this activity, the company strives to improve vessel service performance with the goal of achieving zero waiting time, so that arriving ships can immediately proceed to their next activities, such as cargo unloading for cargo vessels and passenger disembarkation for passenger ships. Similarly, for departing ships, the aim is to minimize vessel queues waiting to use the berth, especially after the completion of cargo unloading operations at the dock.

In vessel service activities at Tanjung Priok Port, PT. P (Regional 2) has not yet optimized the determination of the appropriate number of tugboat units to be operated at the port. The main issue faced by PT. P (Regional 2) lies in the lack of coordination between systems and resources, which results in inefficient vessel service operations at Tanjung Priok Port. This inefficiency causes vessel service time (total time) and vessel waiting time to improve only marginally, despite an increase in the number of tugboats. As a result, the additional tugboat units do not significantly contribute to reducing vessel service time (total time) or waiting time at the port.

One of the reasons for the increase in the number of tugboat units at the port is the high demand for pilotage and tugboat services for vessels entering, shifting, and departing the port. According to data collected by the researcher from PT. P (Regional 2), the number of service requests for vessels entering, shifting, and exiting Tanjung Priok Port in 2019 was 26,690 ships. To meet this demand, PT. P (Regional 2) currently operates 16 tugboat units, of which 13 units are owned by the company and 3 units are leased from PT. P (Regional 2)'s business partners, as illustrated in Figure 4.3. The addition of tugboat units through leasing from external partners was driven by the company's objective to achieve zero waiting time in pilotage and tugboat services. However, the lack of thorough analysis regarding the optimal number of tugboat units needed to serve incoming, shifting, and outgoing vessels has led to inefficiencies in resource procurement.

This inefficiency has resulted in an excess of resources that could have been minimized to achieve the same output. However, PT. P (Regional 2) has made improvements to its vessel service operations by implementing the Marine Operating System (MOS), an application that allows ships to request vessel services online. This system has helped reduce vessel waiting time within the port area, as service requests can now be made before the vessel arrives at the port—unlike the previous manual process, where service requests were made only after the vessel arrived and communicated via radio signal to PT. P (Regional 2).

3.2 Scenario analysis

In this study, the researcher will develop four simulation models consisting of one base case scenario and three proposed scenarios. Each scenario will focus on the number of tugboat fleets operated by Tanjung Priok Port that are used to carry out vessel service activities. The purpose of developing these proposed scenarios is to improve the efficiency of tugboat resources owned by PT. P (Regional 2) by determining the appropriate number of tugboats needed to meet the demand for pilotage and towage services at the port. The proposed scenarios will be based on the analysis results of the base case scenario. If the base case scenario shows that the average total vessel service time and the average vessel waiting time are too long, then the proposed scenario will be designed by adding tugboat units. However, if the results indicate that the average service time and waiting time are already acceptable and all vessels are properly served, the scenario will involve reducing the number of tugboats in order to increase operational efficiency. The scenarios that will be developed by the researcher include the following.

In the proposed simulation, the researcher will develop three alternative scenarios that involve reducing different tugboat units currently leased by PT. P (Regional 2) to support towage activities at Tanjung Priok Port. In Scenario 1, one tugboat unit with a power capacity of 4400 DK will be removed to assess whether this reduction significantly affects the vessel service waiting time and total service time compared to the base case scenario. Scenario 2 involves removing one tugboat unit with a power of 2400 DK to evaluate its impact on port service performance under the same performance indicators. In Scenario 3, one tugboat unit categorized under 1240 DK will be reduced to observe whether eliminating a lower-capacity tugboat influences operational efficiency. All three scenarios are designed to test the sensitivity of the current fleet configuration and determine whether efficiency can be improved by operating with fewer tugboats. Each scenario will be analyzed to identify the changes in system performance, focusing on vessel waiting times and total service durations. The outcomes of these scenarios will be compared with the base case to identify the most efficient configuration.

From all the scenarios developed in this study, the researcher will analyze and compare the simulation results to determine which scenario is the most efficient. The comparison will provide insights for PT. P (Regional 2) in deciding the optimal number of tugboat units required for effective port operations. . This evaluation will also help balance service quality and operational costs by identifying whether fleet reductions can be implemented without compromising performance.

3.2 Research results

Based on the results of the scenario model that has been developed, it can be concluded that Scenario 3 is more favorable compared to Scenario 1 and Scenario 2, as it results in the smallest increase in average total time and shows no significant difference in average waiting time compared to the Base Case Scenario. This indicates that the reduction of one tugboat unit with a power of 1240 HP does not significantly increase the average total time and average waiting time in pilotage and tugboat services at Tanjung Priok Port.

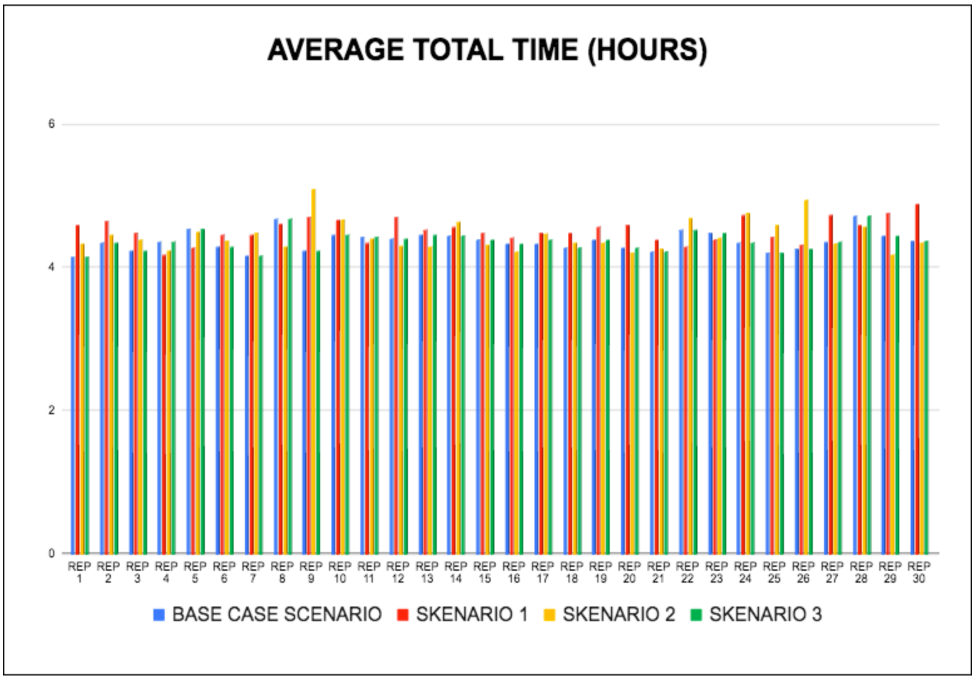

Fig. 1 Comparison of average total time

Figure 1 shows a comparison of simulation results from the developed scenarios, replicated 30 times. The simulation results indicate that Scenario 3 has a total time most similar to the Base Case Scenario compared to the other scenarios. This suggests that PT. P

(Regional 2) can meet the demand for pilotage and tugboat services at Tanjung Priok Port with the same level of performance, even with the reduction of one tugboat unit with 1240 HP capacity.

Based on the analysis of the proposed scenarios, it is observed that the average total time for pilotage and tugboat services at Tanjung Priok Port is 4.3726 hours for the Base Case Scenario; Scenario 1 has an average total time of 4.527 hours; Scenario 2 has an average total time of 4.449 hours; and Scenario 3 has an average total time of 4.3742 hours. Scenario 3 shows the smallest difference from the Base Case Scenario, with a gap of approximately 5.7 seconds.

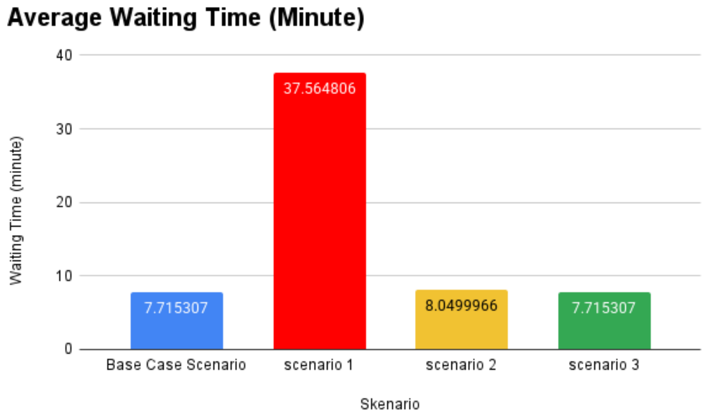

Fig. 2 Comparison of average waiting time

Figure 2 presents a comparative graph of the average waiting time for pilotage and tugboat services across the different scenarios. Based on the scenario analysis results, the average waiting time for the Base Case Scenario is 7.715 minutes; Scenario 1 is 37.56 minutes; Scenario 2 is 8.049 minutes; and Scenario 3 is 7.715 minutes. This indicates that Scenario 3 does not differ significantly from the Base Case Scenario.

In the developed scenario models, the reduction in the number of tugboat units affects the number of vessels served during the pilotage and tugging operations, with each scenario showing a different decrease in the number of "number out" compared to the Base Case Scenario. This highlights the critical role of tugboats in the overall process.

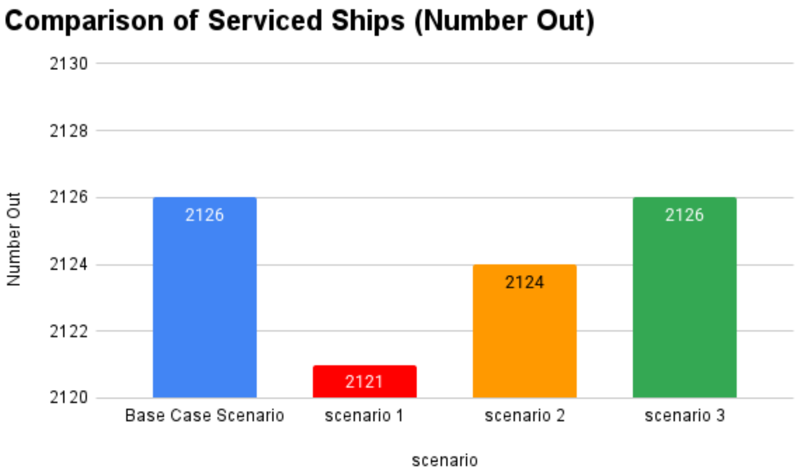

Fig. 3 Comparison of number out

Figure 3 displays a comparative graph of the number of vessels served in response to pilotage and tugboat service requests over a 30-day period at Tanjung Priok Port. The number of vessels served under the Base Case Scenario was 2,126; Scenario 1 served 2,121 vessels; Scenario 2 served 2,124 vessels; and Scenario 3 also served 2,126 vessels. The simulation results indicate that Scenario 3 handled the same number of pilotage and tugboat service requests as the Base Case Scenario. This confirms that the reduction of one tugboat unit with 1240 HP does not affect the number of vessels served under real-world conditions. Therefore, it can be concluded that the rental of one tugboat unit with 1240 HP by PT. P (Regional 2) does not contribute to a reduction in average total time, average waiting time, or an increase in the number of vessels served.

From discussions with key informants, it was explained that the 2400 HP tugboat plays a more critical role because it has nearly twice the power of the 1240 HP tugboat, making it more effective for ship service operations. The 2400 HP tugboat is particularly useful for towing large-category vessels, as it requires fewer units and can perform the task more quickly. Scenario 2 also shows a higher increase in waiting time compared to Scenario 3. Therefore, it is anticipated that implementing Scenario 2 in real-world conditions may result in significantly higher waiting times. Based on these considerations, Scenario 3 is deemed the most feasible and appropriate scenario to implement.

According to the results of interviews with key informants, the annual cost of renting one 1240 HP tugboat is IDR 5,400,000,000 (Five Billion Four Hundred Million Rupiah), and the estimated annual operational costs (including salaries, fuel, and maintenance) amount to IDR 3,464,520,000 (Three Billion Four Hundred Sixty-Four Million Five Hundred Twenty Thousand Rupiah). Therefore, if the company implements Scenario 3 as the recommended decision for determining the number of operating tugboats at the port, it could save approximately IDR 8,864,520,000 (Eight Billion Eight Hundred Sixty-Four Million Five Hundred Twenty Thousand Rupiah) over a one-year period.

4. Conclusion

The objective of this study is to analyze the average total time and average waiting time of pilotage and tugboat services, as well as to determine the optimal number of tugboat units that should be operated at Tanjung Priok Port. To achieve this, a simulation model of the Base Case Scenario was developed and validated, confirming the model's accuracy based on the results of the validation test. The simulation of the Base Case Scenario showed that PT. P (Regional 2) is capable of meeting the entire demand for pilotage and tugboat services at Tanjung Priok Port, as evidenced by the number of "number out" generated by the simulation matching the "number in" of service request entities for inbound, shifting, and outbound vessels, totaling 2,126 ships. The Base Case Scenario simulation results indicate that the average total service time for pilotage and tugging operations is 4.3726 hours, with an average waiting time of 7.715 minutes.

To improve the efficiency of tugboat resource utilization at Tanjung Priok Port, three proposed scenarios were developed by reducing one operating tugboat unit. The scenario analysis results show that Scenario 2 and Scenario 3 do not significantly differ from the Base Case Scenario. Scenario 3 was selected as the recommended scenario because it involves reducing one 1240 HP tugboat unit, which presents a lower risk of simulation error under real-world conditions. The analysis of Scenario 3 shows that reducing one 1240 HP tugboat does not increase the average waiting time or the average total service time, which remains at 4.3742 hours. Therefore, based on the scenario analysis, it can be concluded that PT. P (Regional 2) is still capable of meeting the full demand for pilotage and tugboat services at Tanjung Priok Port, Jakarta, with the same level of performance using 15 tugboat units.

Acknowledgement

The authors would like to express their sincere gratitude to all individuals and institutions who have supported the completion of this research. Special thanks are extended to the staff of PT. P (Regional 2) for providing access to valuable operational data and insightful information. The authors also appreciate the assistance of peers who contributed to language editing and proofreading throughout the manuscript preparation.

Author Contribution

O.H.R.A. was responsible for designing the research framework, collecting and organizing data from port operation records, and drafting the initial version of the manuscript. He also contributed to the development of the simulation methodology, conducted scenario analysis using ARENA software, and revised the manuscript critically for important intellectual content. R.D.K. supervised the overall research design, provided methodological guidance, and contributed to refining the simulation model. She also reviewed and edited the manuscript for intellectual rigor and clarity, ensuring the accuracy and relevance of the findings. Both authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Funding

This research received no external funding.

Ethical Review Board Statement

Not available.

Informed Consent Statement

Not available.

Data Availability Statement

Not available

Conflicts of Interest

The authors declare no conflict of interest.

Open Access

References

Adrian, A. (2022). *Indonesia termasuk?, inilah pelabuhan terbesar di Asia Tenggara*. Master Container. https://master-container.co.id/news-articles/pelabuhan-terbesar-di-asia-tenggara/

Andrianto, Y., Wicaksono, A., & Anwar, M. R. (2017). Analisis kinerja pelayanan pemanduan kapal terhadap waktu tunggu (*waiting time*) di Pelabuhan Tanjung Perak. *IPTEK Journal of Proceedings Series, 3*(5), 50–59. https://doi.org/10.12962/j23546026.y2017i5.3114

Anwar, M. (2022). *40% kargo dunia numpang lewat laut NKRI, RI dapat untung?*. CNBC Indonesia. https://www.cnbcindonesia.com/news/20200824133827-4-181528/40-kargo-dunia-numpang-lewat-laut-nkri-ri-dapat-untung

Azka, R. M. (2020). *Perlu SDM mumpuni jaga kinerja angkutan laut: Ekonomi*. Bisnis.com. https://ekonomi.bisnis.com/read/20201106/98/1314259/perlu-sdm-mumpuni-jaga-kinerja-angkutan-laut

Badan Pusat Statistik. (2022). *Jumlah kunjungan kapal di pelabuhan yang diusahakan dan tidak diusahakan tahun 1995–2017*.

https://www.bps.go.id/statictable/2009/03/06/1418/jumlah-kunjungan-kapal-di-pelabuhan-yang-diusahakan-dan-tidak-diusahakan-tahun-1995-2017.html

Bardi, E. J., Coyle, J. J., Gibson, B. J., & Novack, R. A. (2011). *Transportation: A supply chain perspective* (7th ed.). South-Western Cengage Learning.

Bowersox, D. J., Closs, D. J., & Cooper, M. B. (2020). *Supply chain logistics management* (5th ed.). The McGraw-Hill Companies, Inc.

Brewer, A., & Hensher, D. (2001). Identifying the overarching logistics strategy of business processes: An exploratory analysis. *International Journal of Logistics Research and Applications, 4*(1), 1–41. https://doi.org/10.1080/13675560110037717

Cao, J. X., Lee, D. H., Chen, J. H., & Shi, Q. (2010). The integrated yard truck and yard crane scheduling problem: Benders' decomposition-based methods. *Transportation Research Part E: Logistics and Transportation Review, 46*(3), 344–353. https://doi.org/10.1016/j.tre.2009.08.012

Cheng, T. C. E., Farahani, R. Z., Lai, K. H., & Sarkis, J. (2015). Sustainability in maritime supply chains: Challenges and opportunities for theory and practice. *Transportation Research Part E: Logistics and Transportation Review, 78*, 1–2. https://doi.org/10.1016/j.tre.2015.03.007

Chopra, S. (2019). *Supply chain management: Strategy, planning, and operation* (7th ed.). Pearson Education Canada.

Chryssolouris, G., Makris, S., Xanthakis, V., & Mourtzis, D. (2004). Towards the internet-based supply chain management for the ship repair industry. *International Journal of Computer Integrated Manufacturing, 17*(1), 45–57. https://doi.org/10.1080/0951192031000080885

Coyle, J. J., Bardi, E. J., & Langley Jr., C. J. (1996). *The management of business logistics* (6th ed.). Western Publishing Company.

Damayanti, A. (2022). Bagaimana sektor logistik bantu ekonomi RI ngebut lagi di 2022? https://finance.detik.com/berita-ekonomi-bisnis/d-5884270/bagaimana-sektor-logistik-bantu-ekonomi-ri-ngebut-lagi-di-2022

Direktorat Jenderal Perhubungan Laut Republik Indonesia. (2014). *Transportasi laut, urat nadi perekonomian nasional*. http://dephub.go.id/post/read/transportasi-laut-urat-nadi-perekonomian-nasional-60496

Dwiki, F. (2021). *Analisis perencanaan armada kapal tunda sebagai pendukung operasional pelabuhan: Studi kasus Pelabuhan Tanjung Perak*. Institut Teknologi Sepuluh Nopember. http://repository.its.ac.id/id/eprint/83345

Heilig, L., Lalla-Ruiz, E., & Voß, S. (2017). Multi-objective inter-terminal truck routing. *Transportation Research Part E: Logistics and Transportation Review, 106*, 178–202. https://doi.org/10.1016/j.tre.2017.07.008

Heizer, J., Render, B., & Munson, C. (2017). *Operations management* (12th ed., p. 441). Pearson Education, Inc.

International Maritime Organization. (2019). *Review of maritime transport*. United Nations Publications. https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf

Jia, S., Li, C. L., & Xu, Z. (2019). Managing navigation channel traffic and anchorage area utilization of a container port. *Transportation Science, 53*(3), 728–745. https://doi.org/10.1287/trsc.2018.0879

Jinca, M. Y., Farianto, L., & Aksa, K. (2012). Sistem transportasi laut kawasan timur Indonesia. *Journal of Science and Technology, 3*(2), 47–60. ISSN 1411-4674.

Kang, L., Meng, Q., & Tan, K. (2020). Tugboat scheduling under ship arrival and tugging process time uncertainty. *Transportation Research Part E: Logistics and Transportation Review, 144*, 102125. https://doi.org/10.1016/j.tre.2020.102125

Kementerian Perhubungan Republik Indonesia. (2018). *Empat puluh persen jalur perdagangan dunia melewati Indonesia*. https://www.dephub.go.id/post/read/empat-puluh-persen-jalur-perdagangan-%20dunia-melewati-indonesia

Lam, J. S. L. (2011). Patterns of maritime supply chains: Slot capacity analysis. *Journal of Transport Geography, 19*(2), 366–374. https://doi.org/10.1016/j.jtrangeo.2010.03.016

Lambert, D., & Cooper, M. (2000). Issues in supply chain management. *Industrial Marketing Management, 29*(1), 65–83. https://doi.org/10.1016/s0019-8501(99)00113-3

Li, S., & Jia, S. (2019). The seaport traffic scheduling problem: Formulations and a column-row generation algorithm. *Transportation Research Part B: Methodological, 128*, 158–184. https://doi.org/10.1016/j.trb.2019.08.003

Mimbar Maritim. (2021). *Pelindo IV: Kebutuhan masyarakat memantik peningkatan arus kunjungan kapal 7,23%*. https://mimbarmaritim.com/2021/07/13/pelindo-iv-kebutuhan-masyarakat-memantik-peningkatan-arus-kunjungan-kapal-723/

Osobajo, O., Koliousis, I., & McLaughlin, H. (2021). Making sense of maritime supply chain: A relationship marketing approach. *Journal of Shipping and Trade, 6*(1). https://doi.org/10.1186/s41072-020-00081-z

Polatidis, N., Pavlidis, M., & Mouratidis, H. (2018). Cyber-attack path discovery in a dynamic supply chain maritime risk management system. *Computer Standards & Interfaces, 56*, 74–82. https://doi.org/10.1016/j.csi.2017.09.006

Puspa, A. (2022). *INSA akui kelangkaan kontainer sulit diprediksi*. Bisnis.com. https://ekonomi.bisnis.com/read/20210824/98/1433460/insa-akui-kelangkaan-

Putra, N. (2022). *LM FEB UI umumkan daya saing Indonesia 2020*. Fakultas Ekonomi dan Bisnis Universitas Indonesia. https://www.feb.ui.ac.id/blog/2020/07/18/lm-feb-ui-umumkan-daya-saing-indonesia-2020/

Sari, R. (2011). *Pengaruh ketersediaan fasilitas dan sistem informasi manajemen terhadap waktu kunjungan kapal di Pelabuhan Utama Tanjung Priok* (Tesis, Universitas Trisakti).

Sauri, S., & Martin, E. (2011). Space allocating strategies for improving import yard performance at marine terminals. *Transportation Research Part E: Logistics and Transportation Review, 47*(6), 1038–1057. https://doi.org/10.1016/j.tre.2011.04.005

Song, L., Yang, D., Chin, A. T. H., Zhang, G., He, Z., Guan, W., & Mao, B. (2016). A game-theoretical approach for modeling competitions in a maritime supply chain. *Maritime Policy & Management, 43*(8), 976–991. https://doi.org/10.1080/03088839.2016.1231427

Suntoro. (2020). *Fundamental manajemen logistik: Fungsi logistik dalam implementasi dan operasi* (1st ed.). Kencana A.

Wei, X., Jia, S., Meng, Q., & Tan, K. (2020). Tugboat scheduling for container ports. *Transportation Research Part E: Logistics and Transportation Review, 142*, 102071. https://doi.org/10.1016/j.tre.2020.102071

Wong, C. Y., Boon-Itt, S., & Wong, C. W. (2011). The contingency effects of environmental uncertainty on the relationship between supply chain integration and operational performance. *Journal of Operations Management, 29*(6), 604–615. https://doi.org/10.1016/j.jom.2011.01.003

Zhang, X., Zeng, Q., & Sheu, J. B. (2019). Modeling the productivity and stability of a terminal operation system with quay crane double cycling. *Transportation Research Part E: Logistics and Transportation Review, 122*, 181–197. https://doi.org/10.1016/j.tre.2018.12.003

Biographies of Authors

Obay Haqi Rifan Arief, Department of Management, Faculty of Economics and Business, Universitas Indonesia, Depok, West Java, 16424, Indonesia.

- Email: haqiobay3@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Ratih Dyah Kusumastuti, Department of Management, Faculty of Economics and Business, Universitas Indonesia, Depok, West Java, 16424, Indonesia.

- Email: ratih.dyah@ui.ac.id
- ORCID: 0000-0001-9827-7718
- Web of Science ResearcherID: N/A
- Scopus Author ID: 8215391500
- Homepage: https://feb.ui.ac.id/uploads/2022/03/CV-Ratih-Dyah-K-Mar-2022-for-RPM.pdf