Journal of Science and Engineering

Full Paper

Development Of An Anylogic Simulation Model To Improve Speedboat Passenger Services At Semut Port, North Maluku Province

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Graphical Abstract



Abstract

Semut Port is an important passanger transportation facility that link speedboat operation from Ternate and Sofifi in North Maluku Province, Indonesia. The Increasing mobility of passanger causing the issue of waiting time, delay boarding and congestion during peak periods. In this study a simulation model based on AnyLogic to evaluate the semut port performance on speedboat passenger service with survey data using Discrete Event Simulation (DES) and Agen-Based Modeling to analyze the integration of passanger, speedboats, port facilities and operation personel. The result shows this current system was sufficient in-service operation and reflect the main operational relationships in Semut Port such as the accumulation of passengers, the service processing, the vessel operation and the use of resources. The simulation results showed that the capacity of Semut Port is adequate for the current demand of passengers. However operational performance is greatly influenced by operational performance, peak arrival patterns and service coordination. The number of completed trips increases gradually during the simulation period while the delayed trip is relatively low. This demonstrates that the vessel scheduling system can maintain operational continuity under current demand.

Keywords: AnyLogic simulation, Discrete event simulation, Agen-based modeling, Passenger flow, Speedboat service, Port operation, Semut port

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1. INTRODUCTION

The Semut Port in North Maluku Province has an important role in the distribution of goods through speedboat transportation services and public transportation. The services provided in this port, which is a major transportation artery, are reliable and have a great bearing on the social and economic activities of the area. But the long waiting times, the limited capacity of the facilities and the lack of focus on passenger comfort demonstrate the urgent need to improve the ergonomics and operational efficiency of the ports. Ports are very important links in the chain of maritime logistics and transportation. According to research by the World Bank in 2022 [1], data-driven port management is important in improving service performance, especially in isolated or archipelagic areas such as North Maluku. The transport analysis should take into consideration terminal capacity, scheduling plans and passenger flow management to minimize wait times and queues. Simulation technology based on Any Logic enables the understanding of port operating flows and the suggestion of service enhancements [2}. Any Logic allows for a thorough assessment of passenger waiting times, capacity, and efficiency by modeling the

transportation system in an integrated fashion. Moreover, ergonomic evaluation is important to ensure passenger comfort and worker safety, as human factors play an important role in the operational efficiency of transportation [3][23]. Thus, the goal of this study is to create an Any Logic simulation model that considers both transportation and ergonomic factors to improve speedboat services at Semut Port. North Maluku Province's Semut Port is a strategically important port that facilitates passenger transportation in the area, particularly inter-island speedboat services. Recent advances in smart port concepts underline the importance of data-driven decision-making, digitalization and simulation-based optimization for improving operational resilience, resource allocation and service reliability in maritime transportation systems.[4][5] [22].

Due to North Maluku's archipelagic terrain, which increases demand for maritime transportation, speedboat passenger services are crucial [6]. However, several problems, such as lengthy wait times, traffic in the pier area, and inadequate comfort levels for both passengers and employees, make it difficult for speedboat passenger services to run smoothly at the port. In this regard, it is crucial to create a simulation model that can depict the dynamics of the port transportation system and the interactions between different components, like ships, passengers, and pier amenities, as well as detect possible ergonomic problems that compromise comfort and safety. This study tackles the following fundamental problems considering the background information and literature review provided: 1. What is the impact of speedboat passenger mobility patterns on service efficiency at Semut Port? 2. What are the main obstacles to Semut Port's passenger service operations? 3. How may operational limitations be addressed and passenger services enhanced using an Any Logic-based simulation model?. An essential method for comprehending and evaluating the operational dynamics of public transportation is system simulation. Vehicles, people, infrastructure, and operating laws are just a few of the many entities that make up transportation systems, particularly port services. According to Banks et al. (2014), real systems that change in response to specific events in discrete time can be represented using the Discrete Event Simulation (DES) technique. In this regard, Any Logic, a multimodal simulation platform, may create more accurate and realistic models by combining the DES method with Agent-Based Modeling (ABM) and System Dynamics (SD) [7].

Research has made extensive use of Any Logic-based transportation simulation to test system sensitivity, create policy scenarios, and assess the effectiveness of logistics and public transportation services. According to Borshchev (2013), Any Logic's primary benefit is its capacity to simulate intricate, large-scale agent interactions. Simulations are essential for port research to analyze different delay situations, dock capacity, passenger queues, and the distribution of peak arrival times [8]. This eliminates the need for expensive hands-on tests and enables system planners to make proactive modifications to service design. Digital simulation approaches have increasingly been applied in port systems to evaluate operational scenarios, identify bottlenecks, and support proactive infrastructure planning [9].

Strategically, evidence-based decision making is also made possible by Any Logic-based system modeling. This simulation helps with the sustainable management of port operations by integrating historical data and future possibilities. Long-term, this model can be applied to speed boat services in island regions like Semut Harbor to build infrastructure, manage schedules, and allocate human resources. A computer-based system called a Decision Support System (DSS) integrates data, models, and an interactive user interface to help decision makers in semi-structured circumstances. When it comes to transportation, DSS plays a crucial role in offering a variety of operational policy options, particularly when dealing with capacity constraints, hectic schedules, or the requirement for more services. Turban et al. (2018) claim that by projecting the effects of different alternative solutions, DSS in conjunction with simulation modeling can greatly enhance decision quality [10]. Any Logic is utilized in this study as a component of a DSS in addition to being a simulation tool. The created model can be set up to dynamically receive variable input (such as the number of ships, officers, and check-in time) and generate output in the form of waiting times, facility utilization levels, and service quality. This facilitates the scenario-based decision-making process, which allows decision-makers to assess typical, peak, or disruption scenarios (like extreme weather) prior to developing infrastructure investments or regulations.

Opportunities to create real-time operational dashboards and early warning systems are also presented by the simulation system's incorporation with DSS. For instance, the simulation can suggest preventive measures like adding officer shifts or adjusting departure schedules when the algorithm identifies a possible bottleneck

based on the anticipated number of passengers. The Any Logic simulation model thus transforms into a proactive, data-driven, and adaptable decision facilitator.

2. METHOD

This research evaluates the operational performance, passenger flow characteristics, and ergonomic features of Semut Port using research method of simulation-based modeling and field survey observations. Empirical data collection combined with computational simulation allows for a comprehensive evaluation of the current port system and also provides a mathematical basis for identifying operational limitations and feasible ideas for improvement.

The first research method was carried out in the form of a direct field survey in Semut Port, Ternate, Indonesia. The main purpose of the survey is to collect operational, infrastructural and ergonomic data related to port service procedures, passenger mobility and vessel operations. Field observations must reflect the real behavior of the transportation system, such as differences in passenger arrival patterns, vessel turnaround procedures, waiting periods, and interactions between passengers, employees and port facilities. In the second approach, a simulation model is developed by integrating Agent-Based Modeling (ABM) and Discrete Event Simulation (DES) techniques using AnyLogic software. DES is used to model sequential operational actions such as passenger arrival, ticket verification, boarding, vessel departure and passenger disembarkation. ATM, in contrast, captures the dynamic interactions between passengers, speedboats, port employees, etc. in the meantime. By combining these methods, the model can simulate complex operating conditions and evaluate the performance of the system under different demand scenarios.

2.1. Data Collection

The relevant variables in analysis of marine passenger terminals are: passenger arrival patterns, vessel schedules, service times and capacity characteristics. De Neufville and Odoni (2013) say that the performance of transportation infrastructure depends on the total demand, the distribution of demand over time and the variability of peak periods [11]. Hence, time-dependent data on passenger arrivals are needed, as an average daily demand may underestimate the risk of congestion during peak hours [12].

2.2. Developing Of AnyLogic Simulation Model

AnyLogic simulation software is used to build a dynamic representation of Semut port operation. Hybrid simulation techniques that combine discrete event simulation with agent based modeling have become popular for modeling complex transport systems with multiple interacting entities [13][25]. AnyLogic is an integrated modeling environment which combines Discrete Event Simulation (DES) and Agent-Based Modeling (ABM) approaches and is appropriate for the analysis of transportation systems with multiple interacting components.The development of simulation consists of three main stages: system description, interaction modeling and performance evaluation. DES is appropriate for modeling systems in which operational activities take place as sequential events such as arrival of passenger, ticket inspection, boarding and vessel departure [7]. ATM can model the individual decision-making agents and their interaction in a changing environment. This approach is especially helpful when modeling the movement of passengers and interactions between users and infrastructure [14].

2.2.1. System Overview

The first is to define the operational structure of Semut Port. The simulation model is an illustration of the whole passenger transportation process including arrival and departure patterns of speedboats. Passenger arrival distribution & queue formation Passenger movements in the terminal area. How to validate or inspect your ticket, boarding and passenger transfer procedures, loading and unloading activities between port and speedboat. According to field survey results, each operational activity is modeled as a process element with given service times and capacity constraints.

2.2.2. System Interaction Modeling

The second step considers the interactions between the different actors of the port system. The key players are the passengers who generate demand by queuing and using terminal facilities. Limited capacity and operating hours Transport services Speed boats Port workers who examine tickets and who supervise and help

passengers get on board. The interaction of these agents determines the main indicators of operation, such as waiting time of passengers, vessel utilization rate, berth occupancy, efficiency of boarding, queue lengths development and possibility of congestion formation. The simulation also evaluates cases with multiple speed boat arrivals during similar time periods, to determine whether existing berth and passenger handling capacity can support concurrent operations.

2.2.3. Simulation and Performance Evaluation

The final step is to perform simulation experiments to evaluate the system performance. The analysis is based on; average wait time for passengers, vessel's departure delayed, terminal occupancy level and queue development during peak demand period. The simulation results are used to identify operational bottlenecks and possible improvement strategies such as increasing service personnel, changing boarding procedures, improving passenger circulation design or demand management strategies are evaluated.

3. RESULTS AND DISCUSSION

"Transport terminals are usually evaluated in terms of operational indicators such as passenger throughput, waiting time, service capacity and infrastructure utilization. Recent studies on port management highlight the strong influence of the interaction between infrastructure capacity, service processes and demand variability on operational efficiency [15][21]. Semut Port is one of the main modes of passenger transit between Ternate and Sofifi. The port is at the south of Ternate City and is the principal gateway for inter-island mobility, especially of people from the administrative and commercial hubs of North Maluku. Based on the field findings, Semut Port serves roughly 100 passengers every day. Demand varies according to the daily travel patterns. The layout of the port includes the passenger waiting rooms, ticketing facilities, vehicle access areas and docking facilities for speed boats. The present configuration is shown in Fig. 1.



Figure 1. Semut Port Development Plan

The infrastructure is sufficient for normal operational conditions. Nevertheless, fluctuations in the intensity of passenger arrivals and the schedule of vessels may lead to transient congestions, especially during peak operational periods. Therefore, understanding passenger demand characteristics and service capacity is important to improve port operational efficiency.

3.1. Analysis of Passenger Demand Patterns and Dynamics

The passenger demand is expected between 101 and 200 passengers per day, and the speed boat excursions are scheduled roughly every two hours. This operational regime corresponds to an expected ~50-100 passengers each service interval of two hours. The results of the observed bimodal passenger arrival pattern indicate the need for the inclusion of time dependent demand in simulation models. Demand variation during peak periods is recognized as a major contributing factor to congestion in transportation systems [16]. The distribution of passenger arrivals is not uniform but depends on time. The bimodal daily demand pattern with high passenger concentrations in the morning and afternoon periods is typical of a higher passenger concentration. Therefore,

the simulation model considers a time-dependent arrival distribution to correctly mimic the passenger accumulation and the queue formation. The temporal demand variation is important to be considered, because the average number of passengers per day can underestimate the risk of congestion. Even a system with enough daily capacity can fail to function if a lot of people show up in a short amount of time.

Table 1. Estimated Arrival Rate in Time Periode

Time Period	Estimated Arrival Rate	Pax/ Hours	Remarks
06.00 – 08.00	Low	10 – 25	Preparation
08.00 – 10.00	High / Peak	50 – 80	Peak Hours
10.00 – 16.00	Medium	20 - 30	Regular Operation
16.00 – 18.00	High / Peak	50 – 80	Evening peak hours
18.00 – 20.00	Low	10 – 25	Closing

Peak passenger accumulation can have a substantial impact on the terminal operation. In the absence of adequate demand balancing systems, high arrival rates may lead to:

- Higher passenger density in waiting areas.
- Longer lines to verify tickets.
- Extended boarding times.
- Less passenger comfort.
- Overburdened port staff.

Therefore, the operating capacity must be evaluated against peak demand situation rather than normal daily demand.

3.2. Service Capacity and Speed Boat Turnaround Performance

3.2.1. Fleet Characteristics

Speed boats operating at Semut Port have passenger capacity ranging from 20-40 persons per vessel and regular departure schedules. A single vessel can in theory carry over 240 passengers a day, with a maximum capacity of 40 passengers and about six operational departures a day. Two speed boats are in operation, with a potential daily service of about 480 people per day, which is above the observed demand, of about 200 passengers per day. This means the current fleet capacity is sufficient in terms of total daily capacity.

However capacity adequacy is heavily dependent on operational timing, availability of vessels and synchronization of passenger arrivals. Capacity shortfalls may still occur temporarily if the number of passenger arrivals in a certain time window exceeds the boarding capacity.

3.2.2. Travel Duration and Vessel Turnaround Time

Transit time between ports is between 30 and 60 minutes, resulting in a total round trip time of between 60 to 120 minutes with no operating delays. Each vessel can make about 6 to 8 trips a day under conditions of efficient loading and unloading. But longer passenger screening times, delayed boarding or berth conflicts may limit the effective number of daily voyages.

Therefore, it is an important feature in boosting service reliability without adding more vessels to improve the turnaround efficiency. However, the temporal mismatch between the rates of arrival and service might still lead to operational bottlenecks, even when the predicted daily vessel capacity exceeds the passenger demand. According to queueing theory, congestion develops when the level of utilization approaches the maximum service capacity, despite the average demand being below the total system capacity [17].

3.3. Check-in and Boarding Process Efficiency

3.3.1. Ticket verification and boarding performance

Passenger flow simulation has become an important approach for evaluating congestion formation and improving service performance in transportation terminals [18]. Indeed, the present check-in and boarding procedures take about 5-10 minutes and are relatively efficient under typical operation conditions. The presence of about 3-5 port staff enables for efficient handling of passengers during times of modest demand.

However, in case of concentrated passenger arrivals, the performance of the system can worsen. For example, the average daily capacity is adequate but at peak times about 80 passengers may arrive at the same time resulting in

big lines.

3.3.2. Possible Operational Bottlenecks

However, when the service rates are lower than the arrival rates, the passenger processing facilities become bottlenecks. Queue theory provides us with an analytical framework to compute waiting time, queue length and resource needs [19]. If one staff member can process one client in around three minutes, a single worker can serve about 20 passengers each hour. Therefore, at least 4 personnel are necessary to maintain a balanced service rate in a peak arrival scenario with 80 people to avoid an excessive wait formation.

Thus, the staffing of the passenger traffic is one of the key elements of its efficiency. The simulation model is then used to assess the appropriateness of the current workforce numbers for different demand scenarios.

3.3.3. Service Time vs Arrival Rate Analysis

One of the most important indications of port performance is the ratio of passenger arrival rate to service capacity. If the rate at which passengers arrive exceeds the rate at which they can be processed, lineups will continue to grow until extra service capacity is available. The relationship is evaluated using simulation analysis by comparing: The rate at which passengers arrive in peak hours, service rate for ticketing, ability to board, and number of vessel sailings.

This approach allows to identify important operational situations in which congestion starts and gives quantitative assistance to improvement measures. The results can be useful for future decisions related to personnel optimization, enhancement of boarding system and change of infrastructure for a more effective and passenger centered port operation.

3.4. Simulation Model and Performance Evaluation

The constructed simulation model should be calibrated against observed operational conditions using the simulated results. Model validation is essential to ensure the simulation result accuracy represent system behavior and provide reliable decision-support system [20][24]. Validation indicators could be**;** Average waiting time of passengers**,** Vessel delay in departure**,** Queue length**,** Time to process passengers**.** The validated model can subsequently be utilized for scenario testing, e.g.: More boarding employees.**,** Changes in vessel schedules**,** Improve passenger circulation layout, The introduction of computerized ticketing systems.



Figure 2. Simulation Model input at Anylogic Software



Figure 3. Simulation Model Result

The developed AnyLogic simulation model was validated using several operational performance indicators such as passenger queue length, waiting time, passenger service completion, vessel operational reliability and the level of utilization of port resources. The simulation output gives insight into the dynamic interaction between the passenger arrival pattern, speed boat capacity, check-in processes and the availability of human resources at Semut Port.

The model is assessed based on the principle of simulation-based performance assessment, where the system behavior is analyzed under the present operating conditions before the introduction of alternative improvement scenarios. The selected indicators are the main factors affecting passenger service quality and

operational efficiency, such as congestion formation, service capacity, and utilization of resources.

3.4.1. Analysis of Passenger Queue Length and Waiting Time

The results of the simulation show that passenger queues are formed dynamically in time, depending on the difference between the passenger arrival rate and the service capacity. Figure X shows the simulated queue length during the operational period. During the first period of the simulation the queue grows gradually as passengers arriving are higher than the temporary capacity of the check-in and boarding system. The maximum queue length observed is around 5 passengers, indicating that the existing service arrangement can prevent the accumulation of excessive passengers under normal demand conditions. However, the fluctuations of queue length imply that the congestion risk still depends on the timing of arrivals. If several passengers arrive just before the ship leaves, the queue grows because the rate of arrivals and the rate of service are not equal for a short time. This result suggests that port capacity evaluation should consider not only the daily volume of passengers but also the temporal distribution of arrivals. Such situations are often seen at transportation terminals, where high demand volumes during peak periods cause short-term congestion even when the overall daily capacity is sufficient. The average passenger waiting time is relatively stable and about 30 minutes during the whole simulation period. The waiting time is acceptable for normal operational conditions, but it shows that passenger waiting is strongly affected by vessel departure interval, not only by check-in processing time. The results show that operational scheduling should be improved, for example by increasing the frequency of departures during peak periods or by better matching the arrival patterns of passengers with the availability of vessels, to reduce waiting time.

3.4.2. Analysis of Passenger Arrival, Service Completion, and Rejection

The output "Datang vs. Dilayani vs. Ditolak" shows the relationship between arriving passengers and service completion. The simulation results suggest that the existing service system can serve most of the arriving passengers. The number of passengers served is closely following the passenger arrival pattern, indicating that the existing capacity of vessel and service personnel is generally sufficient. Under normal operating conditions there is no significant rejection of passengers. This result indicates that the current capacity of speed boats (20–40 passengers per vessel) is still sufficient to satisfy the observed demand level. However, the simulation indicates that under abnormal conditions, such as passenger rejection or delayed service, issues can arise ; arrival of large groups of passengers at the same time, delays in the operation of speed boats, reduced staff availability, temporary reduction in vessel capacity. Therefore, while the system we have in place works well enough, there is still a need for operational flexibility to ensure reliable service at peak demand times.

3.4.3. Performance and Operational Reliability of Speedboat Trips

The simulation also measures the operational performance of speed boats by comparing the total number of trips with the number of the delayed trips. The results indicate that the number of completed trips increases gradually during the simulation period while the delayed trip is relatively low. This demonstrates that the vessel scheduling system can maintain operational continuity under current demand. However, the efficiency of passenger boarding still affects vessel delays. by the efficiency of passenger boarding. The operation of the vessel is sequential, and delays in the boarding process can have a direct impact on the subsequent departure schedule: passenger arrival, ticket checking, boarding, vessel departure, and passenger unloading. Therefore, improvements to passenger processing time can have a direct impact on improved vessel turnaround efficiency. The simulation confirms that operational bottlenecks are not always due to a lack of vessel capacity but can also be caused by the coordination of processes between passengers, workers, and vessel schedules.

3.4.4. Analysis of resource use

The utilization analysis assesses the percentage of utilization of berth facilities and port personnel. The simulation results show that the berth utilization is within acceptable limits, which means that the current docking infrastructure has sufficient capacity to accommodate the existing speed boat operations. Personnel utilization, however, exhibits more variation compared to berth utilization. Staff usage is near maximum capacity in peak periods, highlighting the significance of human resources as a more constraining element than physical infrastructure. This result confirms the previous analysis that check-in and boarding personnel have an important impact on passenger flow performance. Thus, improving staff availability during peak periods might be a more effective way to improve than major infrastructure expansion.

3.4.5. Assessment of Simulation Intervention Scenarios

Three intervention scenarios were incorporated in the simulation model to evaluate potential operational improvements:

Scenario 1: More check-in staff

The first intervention looks at the effect of increasing the number of passenger service personnel. Increasing the number of check-in officers can reduce passenger processing time and increase service capacity during peak periods. Expected impact includes decrease of passenger queue length; decrease of average waiting time; improvement of boarding efficiency. This is particularly relevant considering that staff availability is one of the main operational constraints identified from the utilization analysis.

Scenario 2: Additional Capacity of Speed Boat Fleet

The second intervention assesses the effect of increasing vessel availability. The model supposes that increasing fleet capacity improves the ability to transport passengers by around 50 percent. The expected results are less passenger build-up; more flexibility for departures; better resilience of the system against peaks of demand. But considering that the current simulation results show adequate vessel capacity under normal conditions, the benefit from additional vessels may be limited relative to improvements in operational management.

Scenario 3: Strategy for Improving On-Time Departure

The third intervention considers the impact of improved departure reliability. This scenario improves the operational coordination to reduce the probability of vessel delay by approximately 60%. Expected benefits are improved reliability of schedule; reduced passenger waiting time; increased satisfaction of passengers. This example shows that improvements in operational management can yield substantial performance benefits with no major infrastructure investment.

3.4.6. Validation of model and performance evaluation

The simulation model was validated by comparing the model output with the observed operational characteristics of Semut Port. The validation of models is crucial to ensure that the simulation results are representative of the real system behavior [20]. The validation parameters are waiting time of passengers, queue length, delay of vessel departure, processing time of passengers, queue length, delay of vessel departure, processing time of passengers, and utilization of resources. The results of the simulation show that the model can reflect the main operational relationships in Semut Port such as the accumulation of passengers, the service processing, the vessel operation and the use of resources. The simulation results showed that the capacity of Semut Port is adequate for the current demand of passengers. However, operational performance is greatly influenced by operational performance, peak arrival patterns and service coordination. Peak arrival patterns and the coordination of service have a large impact on operational performance. The arrival of peaks and the service coordination have a significant effect on the operation's performance. Therefore, improvement measures should concentrate on optimizing operations through staffing levels, management of departures and improved control over passenger flow rather than increasing infrastructure capacity.

4. CONCLUSION

In this study, a simulation model based on AnyLogic to evaluate the semut port performance on speedboat passenger service with survey data using Discrete Event Simulation (DES) and Agen-Based Modeling to analyze the integration of passanger, speedboats, port facilities and operation personel. The result shows this current system was sufficient in-service operation and reflect the main operational relationships in Semut Port such as the accumulation of passengers, the service processing, the vessel operation and the use of resources. The simulation results showed that the capacity of Semut Port is adequate for the current demand of passengers. However operational performance is greatly influenced by operational performance, peak arrival patterns and service coordination. The number of completed trips increases gradually during the simulation period while the delayed trip is relatively low. This demonstrates that the vessel scheduling system can maintain operational continuity under current demand.

ACKNOWLEDGEMENTS

This study was supported by Universitas Khairun, Fakculty of Engineering from financial support through Program Penelitian Kompetitif Unggulan Perguruan Tinggi (PKUPT). Special thank also to the management of Semut Port for supporting, cooperation and important information to completion this research possible.

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