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DYNAMIC SYSTEM SIMULATION FOR OPTIMIZING THE READY-TO-LOAD PARKING CAPACITY AT THE LCM Wharf, FERRY PORT

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ABSTRACT

The integration of the Trans-Java Toll Road has triggered induced demand and batch arrival patterns at the Ketapang Ferry Port, potentially creating structural bottlenecks due to space limitations.

This study aims to determine the ideal capacity of the 6,170 m² ready-to-load parking area at LCM Piers (IV, V, and VI) to mitigate vehicle queues using a dynamic system simulation method (Powersim).

Evaluation based on daily operational data for normal conditions and the peak season for the March 2026 Eid al-Fitr transportation period indicates that parking performance is ideal for the Class VII vehicle scenario with a Density Index of 0.57 (57% utilized), leaving 2,651 m² of idle space. Conversely, in the Class VIII vehicle scenario, land space utilization reaches saturation with a Density Index of 0.98 (98% utilized), leaving only 2% of the remaining space (123 m²). This critical condition triggers the highest level of warning (critical alarm), because a minor delay in the ship loading process will immediately cause a queue of vehicles to overflow outside the port authority or national road.

INTRODUCTION

Law Number 17 of 2008 concerning Shipping establishes ports as nodes in the transportation network, serving as gateways for national and international economic activities. As a First-Class port, Ketapang Ferry Port holds a legal

mandate to provide reliable and safe port services. Its existence is not merely a physical infrastructure, but also an instrument of economic sovereignty, connecting the land connectivity of Java and Bali. Within the transportation hierarchy, operational failures at this node will impact the regional logistics system, which legally requires port managers to consistently comply with Minimum Service Standards (SPM) to guarantee the rights of service users and the smooth distribution of national staple goods.

The development of toll road infrastructure from the western to eastern tip of Java has created a highly efficient logistics corridor, but this has created new challenges at termination points such as Banyuwangi Regency. The integration of the Trans-Java Toll Road has transformed the map of freight movement; production centers in Java now have direct, high-speed access to the eastern exit. Consequently, Ketapang Port is experiencing non-linear volume pressures. Efficiency at the Ketapang-Gilimanuk ferry crossing is now a key determinant of whether the toll road's efficiency gains can be maintained or lost due to port queues. Macroeconomically, Ketapang is the lifeline for food supplies and construction materials for development in Bali and Nusa Tenggara. Any increase in operational costs due to queues (such as extra fuel consumption and degradation of product quality) will directly contribute to consumer prices. Therefore, maintaining smooth traffic at the Ketapang Ferry Port is a concrete effort to maintain inflation stability in the southern part of Eastern Indonesia.

The presence of toll roads has empirically triggered an induced demand phenomenon, where ease of access actually stimulates vehicle volume growth that exceeds the design capacity of existing infrastructure. At the Ketapang Ferry Port, this is evident in the drastic change in user arrival patterns. Whereas previously vehicle arrivals tended to follow a random distribution spread over time, vehicles now arrive in batches (large groups), driven by the smooth flow of traffic on the toll road. Productivity data from the East Java Class II Regional Ferry Agency (BPTD) provides a clear picture of the significant increase in passenger and vehicle traffic.

The Ketapang Ferry Port, managed by PT. ASDP Indonesia Ferry (Persero), serves the Bali Strait 24/7 using a fixed schedule, a system that demands high precision in berthing time management. However, complexity arises from the diverse characteristics of the operating Ferry Motor Vessel (KMP) fleet, which necessitates the provision of varied docking facilities. The waterside infrastructure at Ketapang Ferry Port consists of Piers I, II, and III which use the Moveable Bridge (MB) system, one Pontoon Pier unit, and three Landing Craft Machine (LCM) Pier units at Piers IV, V, and VI.

LCM piers have a specific role in accommodating heavy logistics vehicles and vehicles with non-standard dimensions (such as Class VII and VIII vehicles). A frequently encountered technical challenge is the difference in loading and unloading duration (clapping time) between these pier types. LCM piers tend to have more fluctuating operational hours due to their high dependence on coastal hydrodynamic conditions, which often trigger long queues in the port area. This operational gap resulting from the variety of pier types and natural conditions

requires a management system and adequate onshore facility capacity to regulate the flow of incoming vehicles before they enter the ship's deck.

In this regard, the ready-to-load parking area, or buffer zone, at the Ketapang Main Class Ferry Port functions as a volume control system. Operations at the LCM piers are supported by a 6,170 m² ready-to-load parking area. Although theoretically, the ready-to-load parking area is specifically allocated for each pier, real challenges arise during peak season periods or peak transportation periods (such as the Eid al-Fitr holiday). Under these conditions, the surge in the volume of vehicles arriving simultaneously (batch arrivals) often exceeds the available static capacity. Infrastructure limitations in handling the surge in traffic during peak season are not simply a matter of queues, but rather structural constraints due to the land area reaching saturation point. Horizontal expansion of the operational area at Ketapang Ferry Port is difficult due to its geographical location, sandwiched between the Bali Strait coastline, the main inter-provincial route, and densely populated residential areas.

Technically, the parking adequacy ratio must correlate with the total ship capacity within a schedule cycle and fluctuations in waiting time (clapping time) at the pier. If the available parking area is smaller than the volume of incoming vehicles within a departure interval, there will be an accumulation of remaining vehicles that continues to increase hourly. This limitation triggers an operational bottleneck: the flow of vehicles accessing the Trans-Java Toll Road (incoming flow) is not commensurate with the speed of ship service at the LCM pier (outgoing flow) during peak season, resulting in the buildup of vehicles that cannot be accommodated in the parking area and overflow onto the access road outside the port authority.

Given the nonlinear, complex nature of these queuing and space constraints, and the interconnected nature of vehicle arrival patterns and the dynamic capacity of the port, conventional static calculation approaches are no longer adequate. Therefore, a sophisticated evaluation methodology using Dynamic System Simulation is required. Through dynamic system modeling, the feedback loop interaction between fluctuations in the volume of logistics vehicle arrivals, the 6,170 m² of ready-to-load parking space, variations in ship clapping time, and ship loading capacity at the LCM pier can be comprehensively simulated. This dynamic system approach is used to optimize the ready-to-load parking space capacity, test load sensitivity, and map operational saturation points between Class VII and Class VIII vehicle scenarios. Recommendations resulting from this simulation aim to ensure that all vehicles can be fully accommodated within the port authority zone without creating externalities to the national highway network.

METHODOLOGY

The main subjects of this study are the dynamic behavior characteristics and level of space utilization efficiency of the landside facilities of the ferry port, specifically represented by the existing 6,170 m² ready-to-load parking area. This area serves as a crucial holding zone serving cargo flows to the docks using the

Landing Craft Machine (LCM) system, covering Pier IV, Pier V, and Pier VI at the Ketapang Ferry Port, Banyuwangi.

In more detail, the technical entities that serve as the focus of observation and driving elements in this system dynamics simulation include:

1. Vehicle Inflow: The arrival pattern of heavy logistics fleets in large groups (batch arrivals) driven by the induced demand phenomenon of the Trans-Java Toll Road corridor;
2. Load Dimension Characteristics: The actual Parking Space Unit (SRP) requirement for large and long-nosed freight transport fleets, limited to sensitivity testing for Class VII and Class VIII Logistics Vehicles.
3. Vehicle Outflow: The rate of emptying of land parking spaces onto the deck of the Ferry Motorboat (KMP), whose performance is directly influenced by fluctuations in the ramp closure duration or the mooring time (clapping time) on the concrete slipway of the LCM pier.

By determining these subjects, this study will mechanically observe the vehicle accumulation (stock) within the static space of 6,170 m² to map the projected Parking Space Density Index and detect the emergence of the Saturated Capacity Point (CPP) in each load class scenario.

The object of this research is all physical components, operational parameters, and circulation systems that shape the capacity dynamics of the land facilities at the Ketapang Ferry Port in Banyuwangi. Specifically, the locus and primary observation material in this system dynamics simulation modeling is the existing 6,170 m² ready-to-load parking area dedicated to serving the operational fleet of Ferry Motorboats (KMP) on the Landing Craft Machine (LCM) Pier route, including Piers IV, V, and VI. Operationally, this research object is examined through the nonlinear interactions between technical variables, including:

1. Static Capacity and Land Spatial Layout: The total available effective area of the existing ready-to-load parking area is 6,170 m² and the Parking Space Unit (SRP) coefficient refers to the spatial dimensions of heavy logistics vehicles;
2. Vehicle Inflow Characteristics: Fluctuations in the volume and arrival rate of logistics sector vehicles in large groups (batch arrivals) per unit of observation time, triggered by the induced demand of the Trans-Java Toll Road corridor;
3. Vehicle Outflow Characteristics: The rate of vehicle loading onto the ferry deck, evaluated based on variations in the duration of the ramp gate opening and closing or the ship's mooring time (clapping time) on the concrete slipway of the LCM pier;
4. Cargo Class Characteristics: Specifications of the dimensions and types of freight vehicles strictly limited to the Logistics Class VII (total length 12 to 16 meters) and Logistics Class VIII (total length exceeding 16 meters) scenarios.

Through analysis of these object variables, this study will test the sensitivity of the port land space load to produce output in the form of Parking Space Density Index values, idle space volume, and mapping the Saturated Capacity Point projections for each load class scenario, both in normal daily operational conditions and during the peak season of Eid al-Fitr transportation.

Research Location: The research location covers the operational and administrative areas related to the Ketapang-Gilimanuk crossing. Banyuwangi Regency is the largest regency in East Java Province and Java Island, located at the easternmost tip of Java Island, precisely at coordinates 7°43' to 8°46' South Latitude and 113°53' to 114°38' East Longitude. Banyuwangi Regency covers approximately 5,782.50 km2, divided into 25 sub-districts and 217 villages/wards. The boundaries of Banyuwangi Regency are as follows:

1. North: Situbondo Regency;
2. South: Indian Ocean;
3. West: Jember Regency and Bondowoso Regency;
4. East: Bali Strait.

This research was conducted in the landside authority area of the Ketapang Ferry Port, Banyuwangi Regency, East Java Province. The scope of the observation location is specifically focused on the existing ready-to-load parking area of 6,170 m² dedicated to serving the flow of cargo to the Landing Craft Machine (LCM) Pier, namely Pier IV, Pier V, and Pier VI. The time of data collection and field observations covers two representative time periods, namely normal daily operational conditions and peak season conditions for Eid al-Fitr transportation in the period of March 2026. Aerial perspectives on the surrounding environmental conditions, parking area zoning, and strategic position.

The existing main facilities at Ketapang Port include a dock area and vehicle parking zone, which are integrated into a single service system. The relationship between static capacity on land and dynamic productivity on the waterfront is crucial for the smooth flow of logistics between Java and Bali. The effective use of these parking areas is a key variable in absorbing fluctuations in vehicle arrivals before they are channeled to the ship's deck via the LCM dock system.

The locations for collecting secondary data to support this research include:

1. East Java Class II Land Transportation Management Agency (BPTD): Served as a source of technical port operational data, dock logbooks, ship operational schedules, and regulations for determining ferry port performance;
2. PT. ASDP Indonesia Ferry (Persero) Ketapang Branch: Served as a source of data on incoming vehicle volume (manifest), effective parking area, dock availability, and fluctuation patterns of vehicle arrivals;

This research was conducted in March 2026, covering a period of field observation to obtain data on peak vehicle arrival times and dock utilization.

This research was conducted in stages, encompassing the entire academic process, from proposal preparation, field data collection, to computer simulation modeling and final thesis report preparation. Specifically, the operational data collection timeline and direct observation of the dynamics of land space circulation in the 6,170 m² ready-to-load parking area across the LCM Pier at Ketapang Ferry Port were divided into two representative observation timelines. The first period focused on recording daily operational data under normal conditions to capture the random characteristics of basic logistics transportation movements. The second period focused on a scheduled peak season for Eid al-Fitr transportation, which was limited to the crossing period during March 2026.

The selection of the observation duration during this period aimed to accurately obtain variations in the fluctuations in the arrival of large groups of vehicles (batch arrivals) as well as extreme conditions of Class VII and Class VIII truck queues, as a basis for input parameters and validation in the Powersim software.

The main instruments used in this study consisted of three types to comprehensively collect financial, perception, and policy data:

1. Primary Data Collection Instrument (Field Survey). The tools and forms used to obtain direct data at Ketapang Port include:

a. Berthing Time Sheet Form, used to record the time a vessel docks, from the first line, through the loading and unloading process, to the last line, to calculate the BOR value;

b. Traffic Tally Sheet Form, used to record the number of vehicles entering the ready-to-load parking zone, classified by Category (I-IX) per specific time interval (e.g., per hour);

c. Distance Measuring Instrument (Digital or Manual Meter) used to verify the effective dimensions of the ready-to-load parking area and the length of the pier if technical data is not available;

d. Stopwatch (or Timekeeping App) to measure dwell time and vehicle waiting time within the parking area;

e. A digital camera/smartphone was used to document the existing condition of the facilities, queue density, and operational activities at the LCM pier.

2. Secondary Data Collection Instruments: Tools for organizing data obtained from agencies (BPTD Class II East Java, PT. ASDP Indonesia Ferry Persero) included:

a. List of secondary data requirements: Daily Manifest Reports, Passenger and Vehicle Productivity, Port Plan/Layout, and Regulations (KP-DRJD 539 of 2022);

b. Use of a spreadsheet application (such as Microsoft Excel) formulated with the BOR formula and parking capacity calculations according to technical standards to expedite data analysis.

The data collection procedure in this study was systematically designed through several chronological stages to ensure the accuracy and validity of the parameters input into the dynamic system simulation model. The entire series of fieldwork instructions and administrative documentation were divided into three main stages as follows:

1. Preparation Stage (Pre-Survey): This stage began with formal permitting from the relevant authorities, namely the East Java Province Class II Land Transportation Management Agency (BPTD) and PT. ASDP Indonesia Ferry (Persero) Ketapang Branch, as the port operator. After the operational permit was issued, a literature review was conducted to map the spatial coordinates of the observation zone and prepare physical survey instruments, including vehicle volume recording forms, dimensional measuring instruments (roll meters), time recording devices (stopwatches), and documentation cameras. This stage also allocated the field surveyors' work hours to ensure continuous data recording at the LCM Piers (Piers IV, V, and VI).

2. Land and Water Survey Implementation Stage (Primary Data): Primary data collection was conducted directly in the port authority area through visual observation and real-time time recording. The surveyor team recorded the batch arrival rate of large vehicles periodically every hour at the entrance gate to the 6,170 m² ready-to-load parking area. Simultaneously, the surveyors classified the types of incoming vehicles based on their heavy logistics load categories, namely Class VII and Class VIII vehicles. On the water side, the mooring time or vessel service time (clapping time) was recorded using a stopwatch, calculated from the moment the KMP ramp door opened on the concrete slipway, during the unloading and loading processes, and until the ramp door was completely closed.

3. Secondary Data Collection and Compilation Stage: This stage was conducted using documentation methods and technical interviews with port operational officers to collect daily vessel manifest data, historical monthly logistics flow data, and a blueprint of the Ketapang Ferry Port's land layout. All collected primary and secondary data were then evaluated, tabulated into a data matrix table, and cleaned of numerical anomalies (data cleaning). This final compiled data was then formulated into constant parameters, inflow rate variables, and outflow rate variables, ready to be integrated into a flow diagram (Stock and Flow Diagram) in Powersim software.

The data analysis technique in this study uses a quantitative approach based on computer simulation modeling to map the dynamic behavior of port land facilities. All compiled operational data will be processed through a series of mathematical analysis and simulation stages in Powersim software, with the following detailed procedures:

1. Quantitative Input Parameter Analysis:

The initial stage of the analysis was carried out by transforming the field survey data into constant numerical parameters and rate variables. The area of the ready-to-load parking area was set at a constant 6,170 m². Next, the actual dimensions of logistics vehicles were calculated based on the functional Parking Space Unit (SRP) coefficient for each group, namely the vehicle length for scenarios Category VII (12–16 meters) and Category VIII (>16 meters). Data on the distribution of vessel mooring times (clapping time) at Piers IV, V, and VI were calculated for their average fluctuation per unit of observation time to determine the deck capacity of KMP vessels on the LCM dock route.

2. Formulation and Running of the Dynamic System Model:

The measured input parameters were entered into the integral differential equations in the Stock and Flow Diagram in Powersim software. Inflow represents the hourly rate of large-scale vehicle arrivals (batch arrivals) due to the impact of the toll corridor (induced demand), while Outflow represents the rate of emptying parking spaces onto the ship deck based on the clapping time cycle. The simulation process was run continuously to project queue movements over time.

3. Statistical Validation Test (Mean Absolute Percentage Error / MAPE):

To ensure the reliability of the model before its use as a policy-making tool, a behavioral validation analysis was conducted. The testing technique was

carried out by comparing the output values of vehicle volumes from computer simulations with actual data on vehicle congestion in the field during the peak season for Eid al-Fitr transportation in March 2026.

4. Sensitivity Analysis of Land Capacity Optimization Scenarios:

After the simulation model passed the validation test, the final analysis technique was to conduct a sensitivity analysis to evaluate the critical limits for the port's land space adequacy. This analysis was conducted by testing two operational policy scenarios: a predominance of Class VII Logistics Vchicles and a predominance of Class VIII Logistics Vehicles. The simulation output from both scenarios was then analyzed using the Parking Space Density Index (the ratio of the required SRP queue area to the existing total area of 6,170 m²) and the volume of idle space. Through this technique, the critical time and volume points that trigger the Saturated Capacity Point and critical alarms can be precisely detected, thus providing a basis for decision-making to mitigate vehicle overflows to prevent them from spilling beyond the Ketapang Ferry Port's authority area or congesting national highways.

RESULTS AND DISCUSSION

Minister of Transportation Decree No. 52 of 2004 concerning the Management of Ferry Ports stipulates that port facilities are based on land and water space requirements, calculated as follows:

1. Parking for Class VII Ferry Vehicles
A = 75 x 42.5 x 1.0 x 1.2

A = 3,825 m2

2. Parking for Class VIII Ferry Vehicles
A = 75 x 59.4 x 1.0 x 1.2

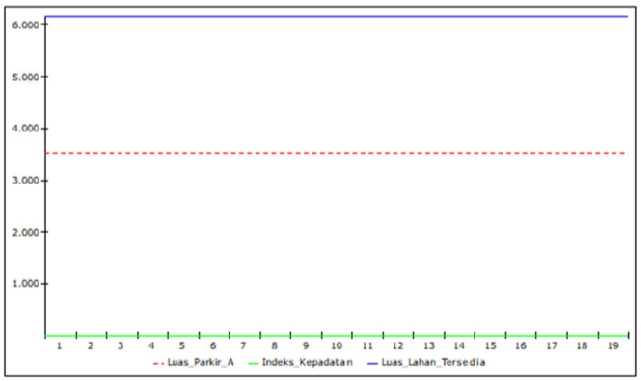
A = 5,346 m2

From these calculations, it can be concluded that to ensure the parallel service of three vessels at the LCM pier without causing circulation obstructions, a ready-to-load parking area with an area ranging from 3,825 m² to 5,346 m² is required. If the actual land area on the ground is smaller than this value, technically there will be a decrease in parking performance, potentially causing vehicle queues to overflow onto the port access road, especially during peak season periods or when Class VIII vehicles are dominant.

The presentation of the results of the dynamic system simulation using Powersim Studio software aims to validate the capability of the ready-to-load parking area of the MB 4-LCM Pier to accommodate vehicle loads in various scenarios as follows:

The model was developed using Powersim Studio software using a Stock and Flow Diagram approach, as shown in Figure 4.5. The model's logical structure integrates the following technical variables:
1. The Land Area variable uses existing data from the MB 4-LCM Pier, amounting to 6,170 m², as the static capacity of available land;
2. The Needs variable is a dependent variable influenced by the number of vehicles per three ships (Total_Vehicles_Ship), Parking Space Units (X_SRP), and the maneuverability coefficient (Y_Coefficient);
3. The Performance Variable (Density_Index) is formulated as the ratio of the required area to the available land area to measure the level of space utilization efficiency.
By integrating technical variables such as the number of vehicles per three ships and the maneuverability coefficient, this simulation provides a visual representation of the threshold for parking capacity on the Ketapang-Gilimanuk route. Parking space performance analysis is conducted using a dynamic system simulation approach to capture system behavior under various vehicle class scenarios. By integrating technical variables such as the number of vehicles per three ships and the maneuvering coefficient, this simulation provides a visual representation of the threshold for the loading parking capacity on the Ketapang-Gilimanuk route below:

1. Class VII Vehicles

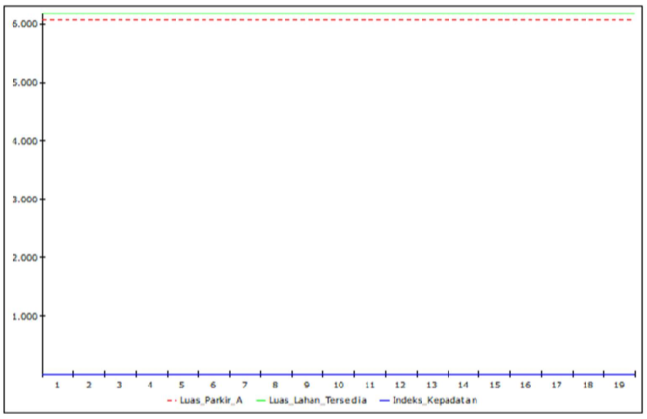


Flowchart (Stock and Flow Diagram) of Variables Determining the Parking Area Ready to Load at the LCM Pier for Class VII Vehicles

Based on the time-series graph visualization of the simulation results, land performance under Class VII vehicle loading conditions shows a very high level of efficiency with a stable area requirement line (red) at 3,519 m². The Density

Index value of 0.57 indicates that the ready-to-load parking area is only 57% utilized, leaving a significant idle space of 2,651 m². The remaining land area technically provides an additional capacity margin capable of accommodating approximately 46 spare Class VII vehicles. This condition creates a wide buffer between space requirements and actual land capacity of 6,170 m², which in transportation engineering represents a Level of Service in the prime category. With very loose maneuvering space, the risk of bottlenecks during the vehicle loading process onto ships can be minimized, while providing resilience for the port system in absorbing fluctuations in vehicle arrivals without triggering queues overflowing the port's main access routes.

2. Class VIII Vehicles



Flowchart (Stock and Flow Diagram) of Variables Determining the Parking Area Ready to Load at the LCM Dock for Class VIII Vehicles

Based on the time-series graph visualization of the simulation results, the land performance in this condition shows a very extreme operational load point, with the area requirement line (red) reaching 6,058.8 m². The Density Index value of 0.98 indicates that the ready-to-load parking area has been used by 98% of the total available capacity. This condition indicates that the parking area is saturated and has almost exceeded the maximum capacity threshold. The remaining free space (idle space) is only 2% or equivalent to 123 m². Technically, this remaining area is no longer able to accommodate additional vehicles in the category of buses or large trucks, and only leaves very limited space for vehicle maneuvers. This situation raises the highest level of warning (critical alarm), where even a small delay in the ship loading process will directly cause queues to overflow beyond the port authority area or main access roads.

CONCLUSION

Based on the results of the system dynamics modeling and simulation analysis using Powersim software on the loading-ready parking capacity across the LCM Pier (Piers IV, V, and VI) at the Ketapang Ferry Port, Banyuwangi, the following conclusions can be drawn:

1. The system dynamics simulation methodology approach has proven highly reliable in accurately representing the nonlinear interactions of port land circulation. The developed model structure is capable of integrating the influence of external variables such as batch arrival patterns and the operational impact of the Trans-Java Toll Road (induced demand) on fluctuations in internal port variables, namely mooring time or vessel service time (clapping time) at the LCM Pier;
2. The results of the load scenario test for Class VII Logistics Vehicles (total vehicle length between 12 and 16 meters) indicate that the static capacity of the existing 6,170 m² of ready-to-load parking area is in very ideal conditions. The simulation parameters recorded a Parking Density Index of 0.57, indicating that the accumulated queues of logistics vehicles on land only absorb 57% of the total effective carrying capacity. This scenario leaves a very safe and adequate amount of idle space, amounting to 2,651 m²;
3. The results of the load scenario test for Class VIII Logistics Vehicles (trailers, trailers, or towing trucks with a total length exceeding 16 meters) indicate a very extreme and critical change in system behavior. Port land space utilization has reached the Saturated Capacity Point, with a Parking Density Index of 0.98 (up to 98% utilization). This condition results in the remaining idle space reaching a very critical level of only 2%, equivalent to 123 m²;
4. The saturation conditions in the Class VIII scenario trigger the highest level of early warning systems (critical maximum-level alarm) for land operations. The remaining 123 m² of free space eliminates the natural capacity of the ready-to-load parking area to absorb fluctuations in cargo movement. As a result, if there is a minor obstacle or even a small delay in the ship's clapping time cycle at the LCM dock, the inflow of heavy logistics vehicles will immediately overflow and cause the vehicle queue to overflow outside the authority area of the Ketapang Ferry Port or jam the national highway network.

The author's recommendations based on the conclusions above include:

1. Considering the margin of error for idle space in the Category VIII scenario is close to zero (only 123 m² remaining), port operators are advised to integrate the digital ferry ticketing system with real-world parking volume data. When Powersim detects the Density Index exceeding 0.80, the system should automatically slow down the flow of vehicles leaving the main ticket counter (toll gate) to prevent deadlocks in the ready-to-load parking area.
2. Redesign operational schedules and group the Ferry Motor Vessel (KMP) fleet at the LCM dock crossing during peak periods. The allocation of ferry vessels with large main deck capacities should be strictly prioritized during peak hours of Class VIII truck batch arrivals to accelerate vehicle outflow.

3. 3. There is a need for standard operating procedures (SOPs) to strictly monitor the opening and closing times of ramp doors on the concrete slipways at Piers IV, V, and VI. Even the slightest reduction in loading and unloading time efficiency will significantly help maintain the stability of land storage volumes, ensuring that the remaining free space does not reach critical limits.
4. As a long-term solution to mitigate queue overflows onto national roads, strategic collaboration between port management and local governments is recommended to activate emergency buffer zones outside the main port area. These external zones will temporarily accommodate the overflow of Class VIII logistics trucks before they are allowed to gradually enter the port's loading-ready parking areas.

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