Analysis of Vehicle Loading and Unloading Operations at the Vehicle Yard of the International Terminal at Tanjung Priok Port in Response to the Surge in Vehicle Volume

Ahmad Zulfadilah[1*], Ulfah[1], Rut Handayani[1], Ramdhani Nur Saputra[1]

[1]Teknik Sipil Politeknik Negeri Ujung Pandang, Makassar, Indonesia

[*]E-mail address: ahmadzulfadilah@poliupg.ac.id

ABSTRACT

The vehicle terminal is a specialized port facility designed for the loading and unloading of Completely Built-Up (CBU) vehicles, trucks, heavy tractors, and spare parts. In Indonesia, the Tanjung Priok Vehicle Terminal is recognized as the second-largest vehicle terminal in Southeast Asia. Indonesian vehicle exports through Tanjung Priok peaked in 2018, reaching 264,533 units. However, the national vehicle import policy has not been supported by the development of domestic manufacturing centers, which has sustained Indonesia's reliance on imported vehicles. Therefore, it is essential to evaluate the capacity of the vehicle storage yard at the Tanjung Priok International Vehicle Terminal to accommodate the projected increase in vehicle volume. This research analyzes the risks associated with yard congestion and assesses the operational management of the terminal to reduce future expansion needs. A multivariate regression model is used to forecast the growth in vehicle throughput through 2030, while a Monte Carlo simulation provides insights into optimizing terminal operation timeframes. The results show that the current yard area is sufficient to meet storage needs based on average operational performance. However, projections indicate that the yard will be unable to accommodate export vehicle volumes by 2026 and total vehicle volumes by 2030, unless operational improvements continue. The analysis also highlights that improved time efficiency in terminal operations can significantly reduce the need for expanding the yard area.

Keywords: *Monte Carlo Simulation, Time Effectiveness, Vehicle Terminals.*

1. INTRODUCTION

Indonesia's strategic location within the Asia-Oceania region positions it as a key player in global automotive logistics. Among its most significant logistics hubs is the Tanjung Priok International Vehicle Terminal, located in North Jakarta. This terminal plays a crucial role in handling the export and import of vehicles, including Completely Built-Up (CBU) cars, trucks, and heavy tractors. It serves not only as a gateway for automotive trade but also as a linchpin in Indonesia's ambition to become a leading vehicle manufacturing and export base in Southeast Asia.

Over the past decade, Indonesia's automotive industry has experienced rapid growth, with domestic production increasing at a compound annual growth rate (CAGR) of 10.2% between 2009 and 2018 [1]. This growth has been fueled by governmental incentives aimed at attracting foreign manufacturers, particularly Japanese and Chinese automakers, to establish local production facilities. Concurrently, export volumes have surged, with 2018 marking a historical peak of 264,533 units exported through the Tanjung Priok terminal.

Policy shifts have also played a pivotal role in shaping terminal operations. The enactment of Directorate General of Customs Regulation No. PER-01/BC/2019 significantly streamlined the export process for CBU vehicles, reducing logistical bottlenecks and encouraging greater throughput. However, this surge in volume has placed increasing pressure on the terminal's yard capacity [2]. The yard, or vehicle stacking area, is essential for the temporary storage of vehicles awaiting customs clearance, inspection, and shipment. Its capacity directly influences terminal efficiency, turnaround time, and operational cost [3] [13].

Given the anticipated increase in vehicle throughput and the physical limitations of the current yard infrastructure, it is imperative to assess whether the existing yard space can accommodate future demands. Moreover, the potential relocation of some operations to the newly developed Patimban Port underscores the need for a comprehensive evaluation of yard availability and operational efficiency at Tanjung Priok.

This research aims to analyze the availability of yard space at the Tanjung Priok terminal in the face of projected increases in vehicle throughput up to the year 2030. Additionally, it investigates how optimizing operational processes, particularly in terms of reducing dwelling time through improved logistics management, can mitigate space constraints [4]. The study employs a multivariate regression model to forecast yard demand and utilizes Monte Carlo simulation to evaluate the impact of operational time efficiency on space requirements.

2. THEORY AND METHODS

2.1 Theoretical Framework

Vehicle terminals are specialized port facilities designed to handle the loading, unloading, inspection, and temporary storage of vehicles. These operations are complex and space-intensive, requiring careful planning and coordination. The primary functions of a vehicle terminal include stevedoring (loading/unloading from ships), cargodoring (movement between the ship and yard), receiving (entry of vehicles into the terminal), and delivery (exit of vehicles from the terminal) [8] [14] [15].

The efficiency of these processes is heavily influenced by yard availability. Yard demand is a function of vehicle throughput, the average time vehicles remain in the terminal (dwelling time), and the spatial requirements of different vehicle types. For example, a CBU may require approximately 13 m^2 of yard space per unit, whereas trucks and heavy tractors require significantly more. As such, forecasting future yard needs necessitates a robust analytical model that accounts for multiple influencing factors [5] [16].

Multivariate regression analysis is particularly suited for this task, as it allows for the modeling of yard demand based on several independent variables simultaneously. These may include domestic vehicle production, export destination GDP, shipping frequency, and more. By understanding the relationship between these predictors and yard demand, port operators can better anticipate and plan for infrastructure needs.

In addition to forecasting, operational optimization is essential. Monte Carlo simulation provides a powerful tool for modeling the variability and uncertainty inherent in terminal operations. By simulating different scenarios of process durations (e.g., customs clearance, loading times), it is possible to identify opportunities for reducing dwelling time. This, in turn, can decrease the overall yard space required, even as throughput increases.

2.2 Methodology

This study adopts a quantitative approach, combining statistical modeling and simulation techniques.

1. Data Collection: Historical data on vehicle throughput, domestic production, GDP of export destinations, and vessel traffic were obtained from PT Indonesia Kendaraan Terminal (IKT), Gaikindo, and national statistics agencies. Data spans from 2010 to 2019.
2. Regression Analysis: A multivariate regression model was developed using SPSS software to forecast yard demand from 2020 to 2030. In this study, SPSS was used to perform a multivariate regression analysis to forecast the vehicle yard demand at the Tanjung Priok Port based on several independent variables. The dependent variable is yard area (m^2), while independent variables include vehicle production, sales, GDP, and port activity [9]. SPSS stands for Statistical Package for the Social Sciences. It is a software package developed by IBM that is widely used for statistical analysis.
3. Simulation Analysis: Monte Carlo simulation was employed to model the operational processes at the terminal. Key processes included in the simulation are receiving, storage, inspection, documentation, and loading. Using @Risk for Excel, multiple iterations were run to estimate the distribution of dwelling times and their impact on yard demand [6] [11] [12].
4. Validation: Model outputs were validated against actual yard usage data for 2019 to ensure reliability.

The forecasting and simulation models employed in this study are subject to several underlying assumptions and limitations. The multivariate regression analysis assumes linear relationships between yard demand and independent variables such as vehicle production, sales, GDP, and vessel traffic. It also presumes the independence and homoscedasticity of residuals, as well as the absence of multicollinearity and the normal distribution of errors. While diagnostic tests indicated acceptable variance inflation factors (VIFs) and a strong model fit ($R^2 = 0.873$), real-world interactions among economic indicators may be more complex and nonlinear. Additionally, the regression model does not account for temporal autocorrelation, which may affect long-term projections. The Monte Carlo simulation assumes consistent statistical distributions for each process segment and independence between them. However, operational delays in one segment often impact others, and external disruptions such as policy shifts or port infrastructure changes may violate these assumptions. Furthermore, the model is limited by the availability of historical data from 2010 to 2019. It also assumes a static yard configuration, which does not reflect potential reconfigurations or temporary expansions. Despite these limitations, the models provide a valuable framework for anticipating yard space requirements and evaluating the benefits of operational efficiency improvements. Future research should consider incorporating real-time operational data, nonlinear forecasting techniques, and contingency scenarios to enhance model robustness.

3. RESULTS AND DISCUSSION

3.1 Forecasting Yard Demand

The multivariate regression showed strong correlations between yard demand and several predictors, with vehicle production and export volume most significant, followed by the GDP of key export destinations (Philippines, Saudi Arabia). The model fit was high ($R^2 = 0.873$). From 2010–2019, vehicle throughput rose steadily, with CBU exports surpassing imports since 2015. Forecasts indicate import yard space will remain sufficient through 2030.

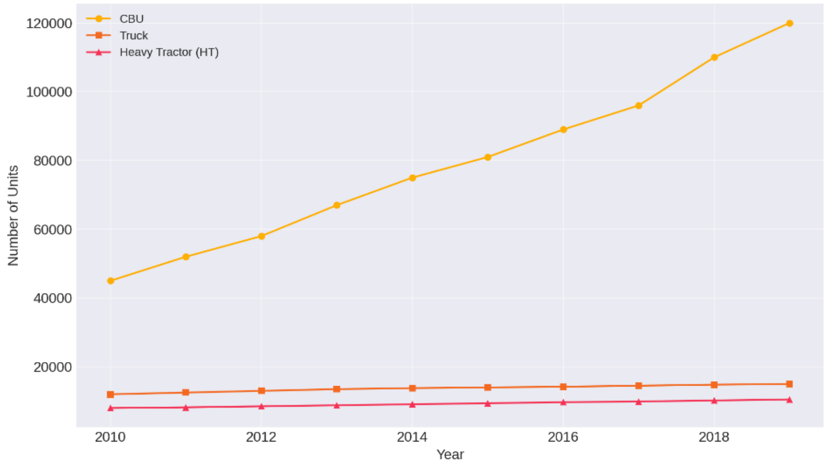

Figure 1. Annual Vehicle Throughput (CBU, Trucks, HT) at Tanjung Priok (2010–2019)

The throughput trend shows a steady increase in CBU vehicles from 45,000 units in 2010 to 120,000 units in 2019, with export volumes surpassing import volumes after 2015. Trucks and heavy tractors (HT) maintained a smaller but consistent share.

Table 1. Regression Model Summary (Export Yard Area)

Predictor Variable	Coefficient (B)	p-value	VIF
Domestic Vehicle Production	0.021	0.003	1.24
Vehicle Sales	0.017	0.012	1.15
GDP (Philippines)	0.089	0.029	1.09
Vessel Traffic	0.312	0.001	1.27

R-squared: 0.873 | F-statistic: 14.87 | $p < 0.001$. Based on the regression model, yard demand is projected to increase steadily, with a critical threshold being crossed around 2026 for export operations. By 2030, total yard demand is expected to exceed the current available area, signaling the need for either expansion or operational reform.

- Import Yard Sufficiency: Forecasts suggest that yard space for imports will remain sufficient until at least 2030.
- Export Yard Deficit: Export yard requirements are projected to exceed capacity by 2026.
- Total Yard Capacity: The combined demand for import and export operations will surpass available space by 2030, necessitating intervention.

However, export yard demand is projected to surpass capacity by 2026, and total yard requirements will exceed the available 110,000 m² by 2030 (Table 2 and Figure 2). This highlights the urgency of evaluating both physical infrastructure and operational efficiency.

Table 2. Forecasted Yard Area Requirement vs Available Yard (2025–2030)

Year	Import (m²)	Export (m²)	Total (m²)	Available (m²)	Status
2025	48,000	55,000	103,000	110,000	Sufficient
2026	51,500	64,200	115,700	110,000	Overload
2027	54,300	69,800	124,100	110,000	Overload
2028	57,100	73,400	130,500	110,000	Overload
2029	59,400	76,800	136,200	110,000	Overload
2030	62,000	79,600	141,600	110,000	Overload

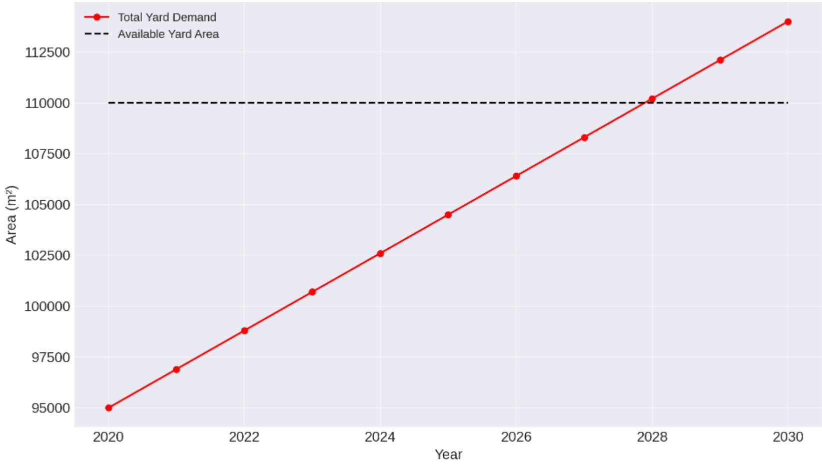

Figure 2. Projected Yard Demand (2020–2030)

The graph illustrates the rising trend of yard requirements, particularly for export operations. This growing disparity highlights the urgent need for strategic planning.

3.2 Operational Optimization via Simulation

To address space constraints without immediate physical expansion, the study incorporated a Monte Carlo simulation to model the variability in dwelling time across six core operational segments: from gate entry to final vehicle exit.

Monte Carlo simulation provided insights into the potential for operational improvements to offset yard constraints. By modeling the duration of key processes (e.g., gate entry to yard, yard to berth), the simulation identified bottlenecks contributing to extended dwelling times [7].

The simulation results demonstrated that with improved coordination, digitization of customs processes, and better scheduling, average dwelling time could be reduced from 5.7 days to approximately 4.2 days. This reduction translates to a 15-25% decrease in required yard area, depending on the operational scenario.

Monte Carlo simulation was conducted for six key process segments in vehicle handling [10] [17]:

- X1: Gate Entry to Unload Line
- X2: Unload Line to Storage
- X3: Storage to Berth (for exports)
- X4: Berth to Storage (for imports)
- X5: Storage to Load Line
- X6: Load Line to Exit Gate

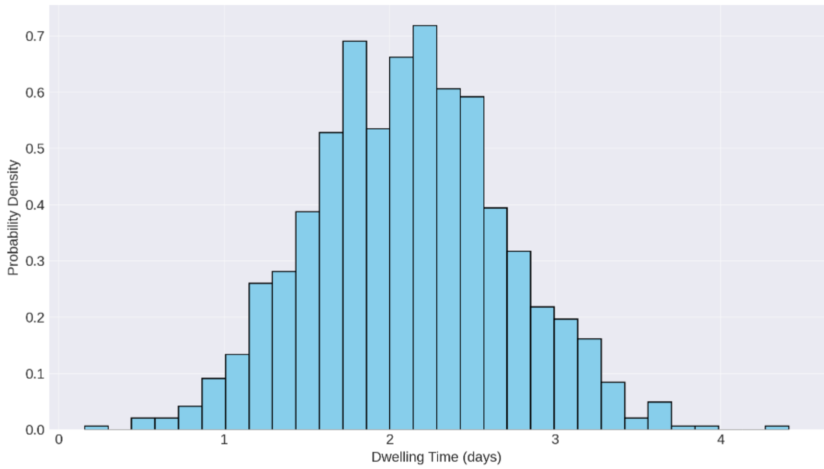

Figure 3. Normal Distribution of Dwelling Time (X2 - Export Vehicles)

The histogram shows a positively skewed distribution with a mean of 2.1 days, and a standard deviation of 0.6 days. Optimization strategies could reduce the tail-end delays.

Table 3. Monte Carlo Simulation Results (Dwelling Time)

Activity Segment	Current Mean (days)	Optimized Mean (days)	Time Saved (days)	Yard Savings (%)
X1	0.8	0.6	0.2	3.2%
X2	2.1	1.4	0.7	12.5%
X3	1.3	0.9	0.4	7.1%
X4	1.1	0.8	0.3	5.3%
X5	0.9	0.7	0.2	3.2%
X6	1.2	0.8	0.4	6.4%

Total Average Time Saved: 2.2 days | Estimated Yard Savings: 18.4%.

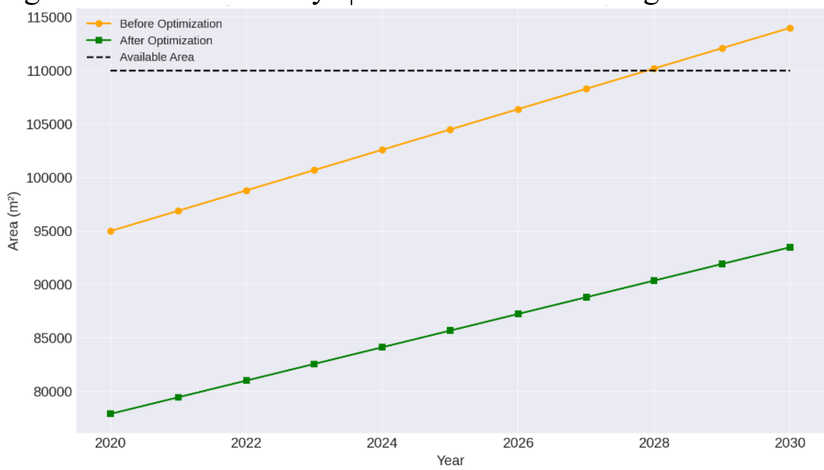

Figure 4. Comparison of Total Yard Demand Before and After Optimization

Monte Carlo simulation was applied to model the duration of six key operational segments, from gate entry to exit, for both import and export processes. The simulation results, summarized in Table 3, indicate that optimizing logistics operations such as through improved coordination, digitization, and process scheduling can reduce the average dwelling time from 5.7 days to 4.2 days. This time reduction corresponds to an estimated yard area savings of up to 18.4%. For example, the X2 segment (unload line to storage) showed the highest potential time savings of 0.7 days, equivalent to a 12.5% reduction in required space, as depicted in Figure 3. The overall impact of these operational improvements is illustrated in Figure 4, which compares total yard demand before and after optimization. The post-optimization projection shows that yard usage remains within capacity limits until at least 2029, even under high-throughput conditions. These findings underscore the importance of integrating time-efficiency strategies as a cost-effective alternative to immediate physical expansion.

These findings reinforce the potential of non-physical solutions, such as workflow restructuring and technology implementation, in extending the operational capacity of existing infrastructure.

Moreover, the simulation highlighted that export operations, which are more complex and time-sensitive, stand to benefit the most from efficiency gains. These findings support strategic investments in technology and process improvement as viable alternatives to physical yard expansion.

Overall, the combined use of regression-based forecasting and scenario-driven simulation provides a robust, data-driven approach to port planning. It not only quantifies the timeline of capacity shortfalls but also demonstrates the tangible benefits of operational efficiency as a short- to medium-term mitigation strategy. This integrated analytical framework can serve as a model for other vehicle terminals facing similar spatial and logistical challenges.

4. CONCLUSIONS

This study concludes that while the current yard capacity at the Tanjung Priok International Vehicle Terminal remains sufficient for import operations, it will become inadequate to accommodate projected export volumes by 2026 and total vehicle throughput by 2030. Through a multivariate regression model, significant predictors of yard demand were identified, including domestic vehicle production, export volume, and the GDP of key export destinations. The forecasting results emphasize the growing pressure on yard space due to increasing automotive trade. However, the application of Monte Carlo simulation demonstrates that operational improvements, particularly those aimed at reducing dwelling time can substantially mitigate space constraints. By streamlining key vehicle handling processes, average dwelling time can be reduced by over two days, resulting in an estimated yard area savings of up to 18.4%. These findings highlight that strategic investments in logistics process optimization and digital terminal management systems can serve as effective interim solutions to delay or minimize the need for physical yard expansion. Overall, the integration of forecasting and simulation approaches offers a comprehensive framework for enhancing the efficiency and resilience of vehicle terminal operations in response to future growth.

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