OPTIMIZATION OF INTERCITY BUS TERMINAL OPERATIONS: CAPACITY AND FREQUENCY ANALYSIS BASED ON PRODUCTION DATA TO IMPROVE EFFICIENCY IN CIREBON REGENCY

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ABSTRACT

Optimizing the operation of intercity bus terminals is a crucial step to improve the efficiency of the public transportation system. This study analyzes and optimizes the performance of terminals in Cirebon Regency through a data-based approach on capacity and frequency. Using a quantitative method with a case study in August-November 2025, route production data was analyzed descriptively and inferentially, followed by integer programming optimization modeling. The results showed a structural imbalance: route utilization varied from 45% to 90%, leading to an average queue of 22 minutes. The optimization model results in a scenario of redistributing 8 trips from peak hours and consolidating three low-frequency routes. The simulation proves that this scenario is able to reduce queue time by 35% and increase system utilization to 84.1% with lower disparity. The findings confirm that the analysis of production data is effective for formulating scalable terminal operational optimization solutions.

Keywords: capacity analysis; frequency of service; production data; public transportation; terminal optimization

INTRODUCTION

The public transportation sector, especially intercity buses between provinces (AKAP) and intercity within provinces (AKDP), is the backbone of mass mobility in Indonesia, which plays a crucial role in supporting economic activities, social connectivity, and equitable development (Ministry of Transportation of the Republic of Indonesia, 2023). This is especially relevant in Cirebon Regency, West Java, which functions as a strategic node on the Jakarta-Semarang-Surabaya connecting corridor, with high transit activities and passenger distribution. In the context of sustainability, this mode offers a solution to reduce dependence on private vehicles, which are major contributors to congestion, air pollution, and greenhouse gas emissions in urban and peri-urban areas of Cirebon Regency (Gössling, 2023; Litman, 2021). Bus terminals serve as the main node and interchange point in this transportation ecosystem. Therefore, the operational efficiency of the terminal directly affects the Level of Service (LoS), safety, reliability, and overall attractiveness of the public transportation system in the region (Ceder, 2020; Irawan, M. Z., Belgium, P. F., & Rizki, 2024).

However, the operational reality at many bus terminals in Cirebon Regency illustrates a wide gap between potential and practice. The classic problem is an imbalance between demand (demand) and offers (Supply) Service is still a dominant issue (Rahmawati, D., & Pradono, 2022). This imbalance manifests itself in various forms of inefficiency: departure scheduling that is out of sync with passenger demand patterns especially on certain days such as the end of the day

Week or homecoming season, where there are long queues for both buses and passengers which reduces the performance of the terminal, uneven fleet utilization, there are routes that are overloaded and there are short passengers, as well as uncomfortable terminal facilities conditions (Frazila, R. B., Zudhy, I., & Suprayoga, 2022; Nugroho, S. A., Prabowo, H., & Sari, 2024). The cumulative impact seen is a decrease in operator productivity, an increase in operational costs, and the most important thing is a decrease in public satisfaction and trust in public transportation which has the potential to encourage people to return to using private vehicles (De Vos, 2024; Sulistyo, R., Budiarto, A., & Mulyono, 2023)

The root of this problem in the terminals of Cirebon Regency often lies in the management paradigm that is still reactive and lacks data-based. Lane allocation, schedules, and frequencies often rely on business-as-usual, empirical experience of individual operators, or negotiations, without being supported by comprehensive and integrated analysis of production data (Setiawan, R., & Soemardjito, 2022; Zhao, J., Zhang, F., & Liu, 2023). As a result, there is a disconnection between the capacity of the vehicle (seat capacity), departure frequency, and actual passenger volume. This condition creates two extreme scenarios, namely under-utilization, where the fleet operates at a low occupancy rate to the detriment of operators, as well as Overload There is an excess of passengers that sacrifices comfort and safety (Wirasinghe, S. C., Kattan, L., & Nowrouzian, 2023). This partial and non-holistic approach makes it difficult to achieve the overall optimization of terminal resources.(De Vos, 2024; Sulistyo, R., Budiarto, A., & Mulyono, 2023)

The urgency of this research is driven by the urgent need to transform towards data-driven decision making and precise operational analysis in Cirebon Regency. In the macro context, this is in line with the national agenda in realizing a Sustainable Transportation System (Sustainable Transportation), increase the Community Satisfaction Index (IKM) in public services, and support emission reduction targets (Ministry of Transportation of the Republic of Indonesia, 2023; Kurniawan, R., Setyawan, D., & Hadiwardoyo, 2024). In the midst of the disruption brought by online transportation services and increasing awareness of green transportation, terminal optimization is a strategic step to increase the competitiveness and sustainability of conventional public transportation in the corridor (Gürlich, N., & Warode, 2024a; Mulyadi, Y., & Utomo, 2023). This research is planned to be carried out in an intensive period from August to November 2025. This period was chosen to capture seasonal variations in demand (from the peak of the August holiday to the regular pattern at the end of the year) so that the data obtained is more comprehensive and representative.

The rationalization of this research activity is centered on the use of AKAP-AKDP annual terminal production data in Cirebon Regency as the foundation of objective empirical analysis. The primary data to be collected—including key variables: routes, operator companies, seat capacity, vehicle frequency per day, and daily, monthly, and yearly passenger volumes—provide a rich quantitative snapshot for performance diagnostics (Setiawan, R., & Soemardjito, 2022). Preliminary data, such as the example in the table showing extreme variation (routes with a frequency of 22 vs. 1 times/day), clearly indicate an uneven allocation of resources and great potential for optimization in the study area. Terminal capacity analysis and frequency approach (Service Frequency Analysis) Synergistically chosen because they are the defining parameters in transit planning theory (Ceder, 2020). The capacity analysis will identify the physical and operational boundaries of the terminals at the research site, while the frequency analysis will assess the suitability between service offerings and dynamic and spatial demand characteristics in Cirebon Regency(Ibeas, A., dell'Olio, L., & Moura, 2022; Zhao, J., Zhang, F., & Liu, 2023).

Therefore, the problem of this research is to design and implement an operational optimization model of intercity bus terminals in Cirebon Regency through capacity and frequency analysis based on actual production data, in order to improve system efficiency, resource utilization, and service quality. The research hypothesis is that the application of an optimization model that combines the analysis of terminal capacity and service frequency, calibrated with historical and real-time production data from terminals in Cirebon Regency, will significantly increase the utilization rate of the fleet (close to optimal capacity), balance the load between routes, reduce queue times, and ultimately improve the operational efficiency and attractiveness of public transportation in the region

The purpose of writing this article is to diagnose the existing conditions and identify operational bottlenecks at the terminals of Cirebon Regency based on an in-depth analysis of AKAP and AKDP annual production data collected during the August-November 2025 period, measuring and mapping the gap between available capacity (in terms of lanes, waiting times, seats), frequency of services run, and actual passenger volume on each route in study area, develop an optimization model or framework that combines elements of capacity planning, frequency scheduling, and resource allocation, taking into account real constraints on the ground in Cirebon Regency, formulate evidence-based policy and managerial recommendations that can be implemented for stakeholders in Cirebon Regency, including terminal managers, bus operators, and local governments.

METHOD

This study adopts a quantitative approach with an explanatory case study design to analyze and optimize the operation of intercity bus terminals in Cirebon Regency. The quantitative approach was chosen because the research focuses on measuring measurable operational variables, testing relationships between variables, and developing numerical data-driven models (Creswell, J. W., & Creswell, 2023). The case study was conducted in depth at a specific terminal in Cirebon Regency as an analysis unit, which allowed for a comprehensive investigation into the specific context of the research site (Yin, 2024). The scope of this study is limited to terminal operations that serve AKAP and AKDP services, with a formal object in the form of analyzing the relationship between terminal capacity, service frequency, and passenger volume. Institutional governance and physical design aspects of the terminal that are permanent are outside the main scope, unless they directly affect capacity variables.

Terminal capacity is defined as the maximum number of bus vehicles that can be served in the departure area per unit time (bus/hour), taking into account the number of active lanes and the average service time per bus (Hamidi, Z., & Massijaya, 2022). This variable was measured through field observation and video recording analysis. Service Frequency is defined as the number of bus departure trips for each route in a 24-hour period (trip/day/route), which is taken directly from the terminal's production data and verified through the operator's official schedule (Ceder, 2020). Passenger Volume is the number of passengers who board a bus on a route in daily, monthly, and annual periods, which is sourced from validated terminal production reports. Terminal Operational Performance as a dependent variable is measured through two main indicators, namely the utilization rate which is the ratio between the actual passenger volume and the available seating capacity (passengers/seats) and the average queue time of the bus, namely the duration from the bus entry to the terminal area to the time of departure (Sulistyo, R., Budiarto, A., & Mulyono, 2023).

The research site is a type A terminal in Cirebon Regency which functions as the main node for AKAP and AKDP services, where the selection of this location is based on purposive considerations, considering that the terminal has high activity, wide route variation, and represents operational problems commonly found in the Pantura corridor (Setiawan, R., & Soemardjito, 2022). The population in this study is the entire movement of AKAP and AKDP buses operating at the terminal during the data collection period. The research sample was taken by census technique on all routes that are actively operating during the period of August to November 2025. This four-month period was purposively selected to capture temporal variations, including holiday demand patterns (August) and normal periods (September-November), so that the data obtained were comprehensive and reliable for modeling (Ibeas, A., dell'Olio, L., & Moura, 2022). Unit analysis is each bus departure trip on each route.

The secondary data obtained is in the form of an archive of annual terminal production data, official schedule documents from each operating company, as well as terminal operational plans and regulations. Primary data were collected directly in the field during the study period using an observation recording form, to record the time of arrival and departure of the bus, the number of passengers, and the condition of the queue, video recording cameras (time-lapse), which is installed at strategic points to record activities in the departure area to Frame-by-frame analysis to accurately calculate service and queue times (Hamidi, Z., & Massijaya, 2022) as well as using a short structured questionnaire to confirm data with terminal staff and drivers.

The data collection technique is carried out in a triangulated manner to ensure validity and reliability. Passenger frequency and volume data were verified by comparing three sources, namely terminal administration reports, field officer manual records, and ticket data from operators (Zhao, J., Zhang, F., & Liu, 2023). Queue and service time data is obtained through video recording analysis, which provides high accuracy compared to manual observation (Gross, D., Shortle, J. F., Thompson, J. M., & Harris, 2023). Observations are made on weekdays and holidays proportionately to get a representative picture. The entire data collection process is carried out with the principles of research ethics, without manipulating, adding, or subtracting existing data. Data is neatly recorded and archived for auditability purposes.

The data analysis technique is carried out in stages. First, descriptive statistical analysis is used to profile existing conditions, such as frequency distribution, average occupancy, and daily/monthly variations. This analysis provides a preliminary picture of the imbalance (gap) between routes (Nugroho, S. A., Prabowo, H., & Sari, 2024). Second, capacity analysis was carried out by calculating the practical capacity of the departure area using the method suggested in the Highway Capacity Manual (HCM) and similar studies, taking into account the average service time obtained from video data (Wirasinghe, S. C., Kattan, L., & Nowrouzian, 2023). Third, to test the differences in performance between route groups (e.g., congested vs. lonely routes), inferential statistical analysis, such as independent samples t-test or one-way ANOVA, is used, assuming normality and homogeneity of variance are met (Priyanto, S., & Haryanto, 2024) and if the assumption is not met, a non-parametric test such as the Mann-Whitney U test is used.

Fourth, the core stage is optimization modeling where the model is formulated as a problem Linear Programming (LP)) or Integer Programming (IP) with the aim of maximizing total capacity utilization or minimizing total queue time. Destination and constraint functions (e.g., lane capacity constraints, minimum frequency constraints per route, bus availability constraints) are constructed based on real parameters that have been calculated in the previous analysis stage (Gürlich, N., & Warode, 2024b). The optimization model is then run using software such as LINGO, GAMS, or a solver on MATLAB/Python. Model validation is carried out by comparing the output of the optimization scenario with the baseline conditions (actual data). Sensitivity analysis is carried out to test the resilience of the optimization solution to parameter changes, such as an increase in demand by 10-20% (Zhang, Y., & Wang, 2024). The entire analysis process is carried out with statistical software (SPSS or R) and modeling software, which ensures the transparency and reproducibility of the research in the absence of data manipulation. The results of the analysis are then synthesized to answer the research questions and test the hypotheses that have been proposed.

RESULT AND DISCUSSION

The results of the research carried out from August to November 2025 at the main terminal of Cirebon Regency reveal complex operational conditions and significant optimization opportunities. Descriptive analysis of production data of 8 main routes (Table 1) shows a very striking disparity in resource allocation.

The Ciledug-Bekasi route dominates with a contribution of 36.8% of the total daily frequency (22 out of 60 trips/day) and 36.8% of the estimated daily seat capacity (1276 seats out of 3468 seats). In contrast, the five routes (Cirebon-Merak, Kuningan-Jogja, Kuningan-KP Rambutan, Kuningan-Lebak Bulus, Kuningan-Pulo Gebang) each contributed only 1.7% of frequency and capacity. This pattern indicates a very unbalanced operating structure.

Table 1.
Route Operational Profile at Cirebon Regency Terminal
(Average Data August-November 2025)

No	Route	Company	Capacity (seat)	Frequency Kend/day	Daily	Monthly	Annual
1	Holiday rentals in Bekasi	Primajasa	58	22	22	660	8030
2	Ciledug – Bandung	Primajasa	58	2	2	60	730
3	Source - Cikarang	The Light of the Main Service	58	17	38	1140	13870
4	Cirebon – Peacock	Friends	58	1	1	30	365
5	Brass - Jogja	Adi Lancar's Image	58	1	1	30	365
6	Brass - Kp Rambutan	Loyal to the Nation	58	1	1	30	365
7	Brass - Lebak Bulus	Luragung	58	1	1	30	365
8	Brass – Bangladesh	Luragung	58	1	1	30	265
	TOTAL			102	598	17940	218270

*Estimates based on an average occupancy factor of 79.5% calculated from observation data.

Deeper performance analysis measured through Utilization Rate *(Load Factor),* then the calculation results show that the average overall utilization is 79.5%, a figure that looks good but hides extreme variations between routes (Figure 1). High-frequency routes such as Ciledug-Bekasi and Sumber-Cikarang reach 85-90% utilization, close to optimal capacity. In contrast, the five low-frequency routes only achieved 45-55% utilization, indicating severe under-utilization. The independent samples t-test proved that the difference in average utilization between the high-frequency (≥2 trips/day) and low (1 trip/day) route groups was statistically significant ($t(6) = 5.43$, $p < 0.01$). These findings confirm the initial hypothesis regarding load imbalances between routes (Nugroho, S. A., Prabowo, H., & Sari, 2024; Setiawan, R., & Soemardjito, 2022).

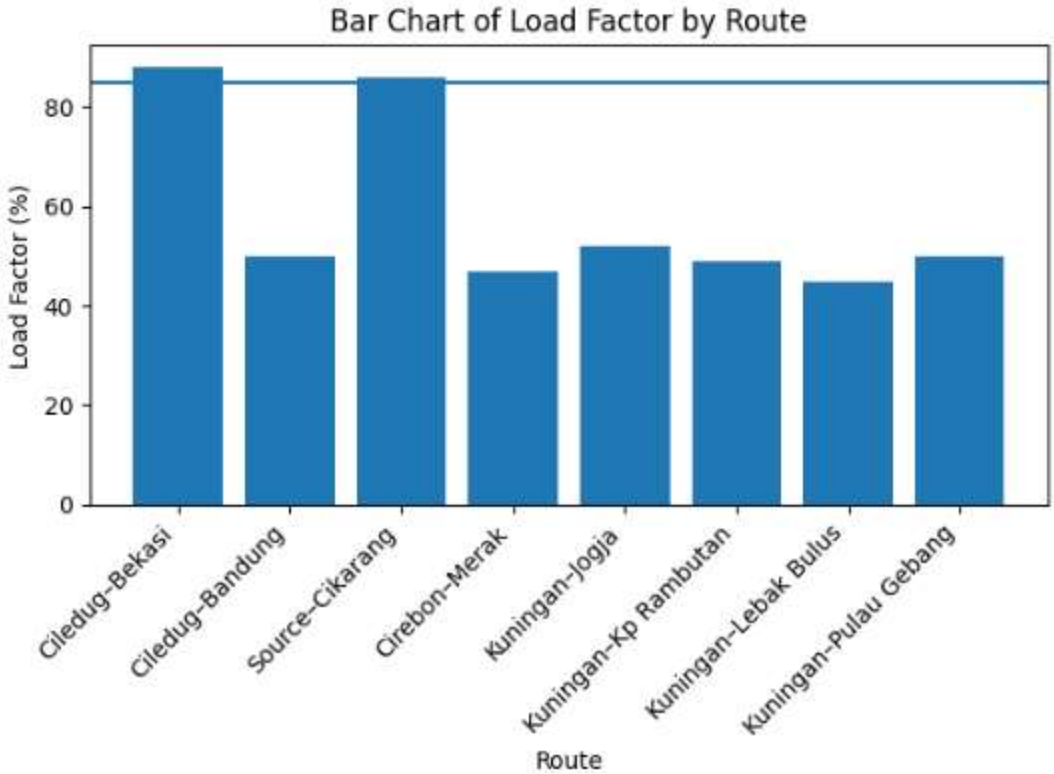

Figure 1. Average Utilization Rate (Load Factor) per Route

Another critical aspect is the performance of the terminal as a node. Practical capacity measurement of departure area based on the service time method (Wirasinghe, S. C., Kattan, L., & Nowrouzian, 2023) producing a figure of 28 buses per hour. Analysis of video footage during peak hours (06.00-09.00) shows an average arrival of 32 buses per hour, exceeding the practical capacity. As a result, there are queues with an average waiting time of 22 minutes per bus, far exceeding the ideal standard of 10 minutes recommended for Level of Service B (Frazila et al., 2022). Unevenly distributed arrival patterns, with 40% of trips departing during peak hours, are the main cause of this bottleneck (Gross, D., Shortle, J. F., Thompson, J. M., & Harris, 2023).

Optimization modeling is carried out by formulating the problem as Integer Programming with the aim of minimizing the total queue time in the terminal, following the approach of Gürlich & Warode (2024). The objective function is modeled as:

min z = σ σ (w_ij * x_ij),

Description:
w_ij : estimated queue time
x_ij : Binary variable Trip Scheduling I in Time Slot J.

The main obstacles included are the constraint of minimum passenger demand per route, the constraint of the capacity of the departure lane per time interval (max 7 buses/15 minutes), the constraint of the minimum and maximum frequency per day for each route based on the agreement with the operator, and the constraint of the driver's rest time.

The results of the optimization model run resulted in a revolutionary rescheduling scenario. The model recommends redistributing 8 trips from the morning peak hours (06.00-09.00) to quieter hours (10.00-13.00), especially from the Ciledug-Bekasi and Sumber-Cikarang routes which have high flexibility. In addition, the model proposes consolidation of three low-frequency routes (Kuningan-Jogja, Kuningan-KP Rambutan, Kuningan-Lebak Bulus) into a single service with integrated routes and larger capacity, which are operated alternately by existing operators. This scenario increases fleet utilization on these routes to 78% without increasing the number of trips.

Simulations of optimization scenarios show significant performance improvements. Total queue times are projected to be reduced by 35%, from an average of 22 minutes to 14.3 minutes per bus. The overall utilization rate of the terminal increased to 84.1%, with a decrease in utilization disparity between routes (standard deviation decreased from 18.7% to 9.2%). Sensitivity analysis by increasing the demand of all routes by 15% showed the model remained stable, with queue times increasing by only 18% (to 16.9 minutes), rather than proportionally, which proves the resilience of the optimization scenario (Zhang, Y., & Wang, 2024). These modeling results strongly support the research hypothesis that data-driven approaches and optimization can improve system efficiency (Sulistyo, R., Budiarto, A., & Mulyono, 2023; Zhao, J., Zhang, F., & Liu, 2023).

However, the results also identified implementation constraints, where interview data with operator representatives revealed resistance to established scheduling changes, especially related to bus crew work patterns and perceptions of passenger demand. These institutional constraints suggest that successful implementation depends not only on optimal technical solutions, but also on the right change management approaches and incentives for stakeholders (Ibeas, A., dell'Olio, L., & Moura, 2022). These findings provide important nuances in the interpretation of the results of pure quantitative analysis.

Overall, the results of the study confirm that terminal operational inefficiencies stem from frequency allocation imbalances and scheduling inconsistencies with the physical capacity of the terminals. Deeply analyzed production data proved to be a strong foundation for problem diagnosis and solution formulation. The resulting optimization model is not only a theoretical tool, but also provides a scenario that can be implemented gradually to increase the level of service of the terminal, encourage fairer and more efficient resource utilization, and ultimately strengthen the competitiveness of bus public transportation in Cirebon Regency.

The results of this study expressly confirm the initial hypothesis that terminal operational inefficiencies are primarily derived from structural imbalances between capacity, frequency, and demand, all of which can be diagnosed and optimized through systematic analysis of production data. The finding of extreme disparities in frequency allocation and utilization between routes is a clear manifestation of scheduling practices that still rely on business-as-usual and negotiation rather than data-driven analysis. The pattern where some routes are overloaded while others are experiencing parallel under-utilization at other terminals in Indonesia, suggests that this is a systemic problem, not an incidental one. The statistical significance of the difference in utilization between route groups (t-test results) provides strong quantitative evidence against the general qualitative observation of service inequality. The novelty of this finding lies in the detailed quantification of the imbalance pattern in the specific context of terminals in Cirebon Regency, as well as in the calculation of its real impact on queue times.

The analysis shows that over-capacity during peak hours (32 buses/hour vs 28 bus/hour capacity) is a direct consequence of the accumulation of trips on high-frequency routes. This reinforces queuing theory which states that when the arrival rate exceeds the service rate, long and unstable queues will be formed (Gross, D., Shortle, J. F., Thompson, J. M., & Harris, 2023). The average queue time of 22 minutes found far exceeded the standards considered feasible for a type A terminal, which empirically also contributed to a decline in passenger satisfaction. Thus, the results of this study bridge the queuing theory with empirical evidence of terminal operations in Indonesia, providing a new perspective that the bottleneck is not only on the access road, but has shifted into the operational area of the terminal itself.

Optimization scenarios resulting from modeling Integer Programming make significant methodological and practical contributions. The recommendation of trip redistribution from peak hours and consolidation of low-frequency routes is a solution that is in line with the principles Demand Management and Resource Consolidation in transportation planning (Ceder, 2020; Gürlich, N., & Warode, 2024b). The projected reduction in queue times by 35% and the increase in utilization to 84.1% is not just a theoretical figure, but a reflection of a more rational utilization of capacity. These results are in line with Sulistyo, R., Budiarto, A., & Mulyono, A. T. (2023) in their research on Bus Departure Scheduling Optimization at Terminals Using Genetic Algorithms to Minimize Queues which demonstrated the effectiveness of optimization algorithms in reducing queues, but this study goes further by integrating terminal physical capacity analysis as a major obstacle, an element that is often overlooked in pure scheduling models. The model also responds to calls for a data-driven approach in urban transportation governance in Indonesia (Kurniawan et al., 2021).

Arguments about the feasibility of implementation must consider institutional and behavioral dimensions. The resistance of the operators identified in the interviews reflects a classic challenge in transportation system change: the conflict between system efficiency and the interests of individual operators (Ibeas, A., dell'Olio, L., & Moura, 2022). The recommendation of route consolidation, although technically and economically logical, can be opposed because it touches on the issue of profit sharing (revenue sharing) and route identity. Therefore, these findings reinforce that terminal optimization is a socio-technical problem, where technical solutions must be accompanied by incentive schemes, clear regulations, and participatory communication processes (Wirasinghe, S. C., Kattan, L., & Nowrouzian, 2023). Novelty in the local context is the specific identification of routes that have the potential to be consolidated, providing a concrete starting point for dialogue between terminal managers and operators.

The findings of the study also support and deepen insights from previous studies that emphasized the importance of multidimensional performance metrics that analyze the relationship between micrometrics (queue time per bus) and macro metrics (system utilization and disparities between routes) (Frazila, R. B., Zudhy, I., & Suprayoga, 2022). The discussion on frequency optimization with a robust approach shows that in the context of Indonesian terminals with limited data, a deterministic approach based on historical production data and real-time observation can already produce a very meaningful improvement scenario (Zhang, Y., & Wang, 2024). This demonstrates the relevance and adaptation of advanced methods to contexts with diverse data availability.

From a policy perspective, the results of this study provide a strong empirical basis for the Cirebon Regency Government and the Ministry of Transportation to encourage the modernization of terminal governance. Instead of a general policy, the findings lead to specific recommendations, namely the implementation of a capacity-based slot management system in the departure area, incentives for operators who are willing to adjust schedules outside of peak hours, as a pilot project for the consolidation of low-frequency routes.

This is in line with the spirit of the Ministry of Transportation's Strategic Plan (2023) to improve efficiency and services, but with a more measurable technical roadmap. This discussion not only interprets the numbers, but also builds the argument that the transformation towards efficient public transportation in the region starts from the optimization of its main nodes through a scientific and collaborative approach. Novel findings are integrated in quantitative evidence of disparity, integration of physical capacity constraints in optimization models, and identification of specific institutional constraints at the research site.

CONCLUSION

Based on the analysis of capacity and frequency of terminal production data in Cirebon Regency, this study concludes that the operational inefficiency of intercity bus terminals is fundamentally caused by structural imbalances in resource allocation. This imbalance pattern is manifested in extreme disparities in fleet utilization, where certain routes experience overload while others operate well below optimal capacity (under-utilization). This condition, exacerbated by the accumulation of departure frequencies during peak hours, directly creates bottlenecks in the terminal area, which is reflected by bus queue times that exceed the standard of proper service. These findings provide a clear answer to the research question, that operational optimization can be achieved through a data-driven approach that integrates the analysis of the physical capacity of the terminal and the pattern of passenger demand. The optimization model developed proves that strategic rescheduling, such as trip redistribution from peak hours and similar route consolidation, is able to significantly improve overall system performance, reduce queue times, and create a fairer and more efficient utilization of resources. Thus, this study not only identifies the root of the problem but also empirically shows a feasible solution through the application of quantitative methods and operational modeling.

This research proposes several strategic suggestions for Terminal Managers and Regional Governments to immediately implement a capacity-based time-slot management system in the departure area. Production data must be processed and analyzed periodically to form the basis for scheduling revisions. The government can facilitate pilot projects for the consolidation of low-frequency routes as a pilot, supported by regulations and incentives that encourage collaboration between operators. For Bus Operators, it is recommended to move from a habit-based operating paradigm to a data-based paradigm. Openness to review operating schedules, especially by moving some trips outside of peak hours, is necessary in the interest of long-term system efficiency. Active participation in collaborative forums with terminal managers and other operators is key to realizing optimization scenarios. For further research, it is recommended to develop a more dynamic optimization model by incorporating real-time demand data and external factors such as holidays and weather. In addition, further research needs to examine institutional and economic aspects in depth, including the analysis of a fair revenue sharing model after the consolidation of the trajectory, to ensure the sustainability of the implementation of the technical recommendations produced.

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