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Enhancing Regional Competitiveness through Intermodal Logistics: A Case Study of Central Java

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Abstract

Focusing on Central Java, this study presents a regional case study of logistics route optimization. Logistics inefficiency remains a critical bottleneck to regional competitiveness in Indonesia, particularly in provinces like Central Java, where dense population and industrial activity demand high-performing transport systems. This study explores the potential of intermodal logistics (integrating rail and road transport) to reduce distribution costs and enhance supply chain sustainability. Using Dijkstra's algorithm on a custom-built transport network graph derived from OpenStreetMap data, we simulate logistics costs across 16 districts in Semarang City under two scenarios: direct road transport and intermodal routing via Semarang Tawang Station. The analysis incorporates vehicle capacities, fuel consumption rates, and population-based demand estimates to calculate total delivery costs, revealing that intermodal solutions yield substantial savings in most districts. Statistical testing confirms the significance of these cost differences. Unlike previous studies, this research contributes to the literature by providing a network-level, cost-optimization assessment of logistics modal in a regional context. Key policy recommendations include developing intermodal hubs, upgrading rail access, and tailoring vehicle deployment to local infrastructure constraints. This study not only contributes to the academic discourse on transport optimization and sustainable logistics but also provides actionable insights for planners and decision-makers aiming to enhance regional connectivity and reduce logistics burdens on businesses.

Keywords: *Intermodal Logistics, Dijkstra Algorithm, and Transportation Optimization*

JEL Classification: *R41, R42, R58, and C61*

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Introduction

The Fourth Industrial Revolution is accelerating globalization and driving significant growth in the logistics and supply chain management sectors. Growing global trade and customer expectations are pushing the demand for delivery solutions that are faster, more reliable, and cost-effective, particularly as distribution costs often represent the largest portion of expenses within the supply chain. Delivering goods requires intensive labor, which makes optimizing route planning essential to reduce logistics expenses. Java, home to 75% of Indonesia's industrial activity, plays a central role in national logistics. Its dense population and industrial hubs rely heavily on major ports. Among these, Tanjung Emas Port stands out with significant hinterland potential, benefiting from its extensive land area, adequate facilities, and infrastructure, along with support from nearby production centers. Its strategic location within the Kendal-Demak-Semarang-Ungaran-Purwodadi (Kedungsepur) regional system further strengthens its potential in the economic development of Central Java (Central Java Government, 2008). However, several areas in Central Java have yet to be integrated with the Tanjung Emas port area, resulting in poor connectivity, which has increased logistics costs. Central Java needs better integration with Tanjung Emas through strategic transport planning that ensures high service standards to optimize logistics performance and minimize goods loss and damage.

Road transportation by truck is still the main mode for logistics distribution in Central Java, with the number of trucks increasing from 521,922 in 2017 to 608,968 in 2022, a growth of 16.68% (SIK et al., 2024). While road transportation is the main mode, it also presents several significant flaws. Many outdated vehicle fleets operate without fuel-efficient engines, causing higher fuel consumption and increased operational costs. Additionally, illegal practices such as over-dimensioning and overloading are causing road damage and accidents. Along with frequent congestion, these issues result in delays and cost-effectiveness of road logistics. Under these conditions, even if the road transportation mode offers flexibility by easily navigating narrow or congested routes and direct access, it is limited in terms of efficiency and economic aspects.

Shifting from road to rail transport offers a promising alternative for moving larger volumes of goods with reduced risks. The Semarang Tawang–Tanjung Emas railway line strengthens this potential, though it still falls short of the direct access and flexibility offered by road transport. To maintain efficient logistics operations, PT. Kereta Api Indonesia needs to collaborate with third-party trucking companies. Reducing reliance on single-mode transport through integrated intermodal systems offers benefits, including lower emissions, accidents, and congestion, and warrants further research. This study aims to develop an optimal logistics route plan from Tanjung Mas Port, minimizing total costs and identifying the most effective transport modes across Central Java.

A literature review on transportation modes was conducted to define the research case and framework. Most intermodal research, as reviewed by Kine et al. (2022), originates from high-income countries, while low-income nations struggle due to limited resources and infrastructure. These constraints require careful consideration of transportation costs, environmental impacts, and the availability of infrastructure and facilities. While traditional models focus on minimizing time and distance, advancements in technology have introduced machine learning for more complex routing. Intermodal transport adds complexity by requiring coordination across modes, underscoring the need for effective algorithmic solutions. One widely used method for route planning involves using Dijkstra's algorithm, with the key advantages being its computational efficiency and reliability. This algorithm is widely used for its efficiency, adaptability, and ability to handle multiple criteria, making it suitable for optimizing routes in both single and intermodal logistics, as evidenced by multiple research studies written by Zhou and Zhang (2023), Lusiani et al. (2021), and Guo et al. (2024).

As a country with a large economic potential and diverse geography, Indonesia has made developing the logistics sector one of its main priorities in efforts to increase its economic competitiveness. The past research has identified logistics efficiency and effectiveness as the key outcomes of competitiveness (Forslund, 2012). In this study, competitiveness is assessed at the regional level, focusing on how effectively transport routes and modes support logistics activities across Central Java. Within the context of intermodal transportation, the integration of road and rail networks plays a crucial role in reducing total logistics costs, improving port–hinterland connectivity, and enhancing supply chain reliability. These improvements contribute directly to strengthening regional economic competitiveness. However, freight transport in Central Java remains heavily dependent on road transport, resulting in high logistics costs and various negative externalities. Although rail infrastructure is available, its utilization for freight transport remains limited due to weak integration with road networks and the absence of systematic, optimization-based route planning.

To address these challenges, this research does not introduce a new method but rather conducts a comprehensive case study to compare transportation modes. Our investigation focused on determining the most suitable transportation route for logistics distribution from Tanjung Mas port to each district in Central Java. The main objective is to identify the optimal route and mode that minimizes transportation costs and improves efficiency.

By advancing scientific knowledge through the implementation of methods for route optimization and providing valuable insights into integrating transportation solutions, the study addresses key logistical challenges faced in the region. The findings will play a crucial role in strategic planning and execution, leading to a transportation system that emphasize enhanced efficiency, sustainability, and reduced distribution costs.

Literature Review

Theoretical Review

Intermodal logistics refers to the integrated use of multiple modes of transportation, such as rail, road, and sea, to move goods from origin to destination seamlessly and cost-effectively. A key characteristic is that the goods themselves are not handled during transfers between modes. Compared to single-mode road transport, intermodal operations are inherently more complex, relying on the coordinated efforts of multiple actors and a clear division of tasks among them. Structurally, a complete intermodal chain integrates several segments: the first mile (prehaulage), the transshipment, the main run, another transshipment, and the last mile (end-haulage) (Faulin et al., 2019).

The theoretical foundations of mathematical modeling in transportation systems provide an essential basis for analyzing and optimizing logistics networks. Such models have been widely applied to the management of transportation and logistics processes at the enterprise level, the analysis of vehicle queuing systems at cargo terminals, and the optimization of passenger and freight transport routes. These applications demonstrate the usefulness of mathematical modeling in improving the efficiency, reliability, and cost of transport systems (Chislov et al., 2021).

In transport logistics research, many optimization problems are addressed using well-established theoretical frameworks that offer efficient solution algorithms. Graph theory specifically serves as a fundamental methodological approach for modeling transport networks and solving routing problems, including shortest path determination, cost minimization, and flow optimization (Kanchana & Kavitha, 2020). Transport networks can be represented as weighted graphs, where nodes correspond to logistics facilities or regions and edges represent transport links associated with costs or distances (Grujic & Grujic, 2025). This representation enables systematic evaluation of alternative routes and transport mode combinations.

The application of graph-based models is especially relevant in the context of intermodal freight transport, where road and rail networks must be integrated into a unified logistics system. In such systems, transport networks function as critical components of regional economic stability, as their performance directly affects supply chain costs, reliability, and risk exposure (Anbri et al., 2025). Efficient transport network configurations contribute to reduced logistics costs and improved connectivity between ports and hinterland regions, thereby supporting regional competitiveness.

In line with this theoretical foundation, this study applies graph theory–based route optimization to evaluate freight transport from Tanjung Mas Port to regional destinations in Central Java. The analysis focuses on minimizing total transportation costs by comparing road-only and intermodal (road–rail) route alternatives. By incorporating intermodal connectivity into the network structure, the study extends traditional route optimization approaches to address practical logistics challenges, such as container transport efficiency and modal integration. This approach provides a quantitative basis for identifying cost-efficient logistics corridors and supports strategic decision-making aimed at improving regional logistics performance.

Empirical Review

Empirical studies on intermodal logistics have predominantly emerged from high-income countries with well-developed infrastructure, such as those in Europe and North America. These studies consistently demonstrate that intermodal systems can reduce logistics costs by 15–30% compared to road-only transport, while also lowering greenhouse gas emissions and road congestion (Kine et al., 2022). Previous studies have applied a wide range of analytical approaches, reflecting the complexity of modal choice decisions. Several studies have examined the interaction between road and rail transport in logistics planning. For example, Wehrle et al. (2023) analyzed modal integration, highlighting the importance of cost and infrastructure availability. These studies provide valuable insights into the strategic considerations underlying road-rail integration. Other researchers have expanded the analysis toward multimodal and sustainable freight transport. Studies by Ishfaq & Sox (2010) employed multiple criteria in intermodal logistics, including financial, operational, and service aspects. While these approaches offer a comprehensive evaluation framework, they primarily focus on identifying strategic cities for hub locations rather than identifying cost-minimizing logistics routes within a network structure. Regional case studies have also played an important role in understanding freight transport decisions. Research by de Souza et al. (2021) demonstrated how regional characteristics, infrastructure availability, and spatial structure influence transportation mode choices. These studies underline the significance of context-specific analysis but often stop short of integrating shortest-path or cost-optimization algorithms to identify optimal intermodal routes. This study adopts a graph theory–based route optimization framework to evaluate intermodal freight transport in Central Java. Rather than ranking modes based on preferences or criteria weights, the study focuses on identifying cost-minimizing logistics routes by explicitly modeling road and rail networks and their interconnections. By applying Dijkstra's shortest path algorithm to a regional case study centered on Tanjung Mas Port, this research complements existing modal choice literature and provides a quantitative, network-level perspective on how intermodal logistics can enhance regional competitiveness through improved logistics efficiency.

Table 1. Data Sources

Data	Data type	Source	Description
Roads	Graph	OpenStreetMap	To calculate the shortest routes, data from roads, railways, and train stations was integrated to form a transportation network graph.
Railways	LineString	OpenStreetMap	
Train Station	Point	OpenStreetMap	
District Population	Table	Ministry of Home Affairs	The population of each district was used as a proxy of demand, helping to estimate the volume of goods needed in different areas.
Administrative Border	Polygon	Geospatial Information Agency Indonesia	Defining precise destination points for logistic transport

Proposed Methods

Data

This research primarily utilizes geographic data gathered from publicly available sources, such as OpenStreetMap, the Ministry of Home Affairs, and Indonesia's Geospatial Information Agency. A detailed overview of the data source and its specifics is provided in Table 1. The study area focuses on Central Java, located in the middle of the island of Java, and serves as a vital hub for national logistics, with a complex network of roads, railways, and ports that support the movement of goods, as shown in Figure 1.

Assumptions and Implications

The study is conducted under several assumptions that reflect data availability and the analytical scope of the research. Transportation load capacity and fuel consumption are treated as consistent values based on typical operational characteristics reported in prior logistics and transportation studies and reflect the limitations of available secondary data. Table 2 summarizes the assumed load capacities and fuel consumption rates used in the analysis.

The use of fixed load capacity and fuel consumption values implies that transportation costs are estimated under static and deterministic conditions. This approach allows for a clear comparison between road-only and intermodal (road–rail) transport alternatives by isolating the structural cost differences between modes. However, operational factors such as partial loading, empty returns, traffic delays, and service frequency are not explicitly modeled.

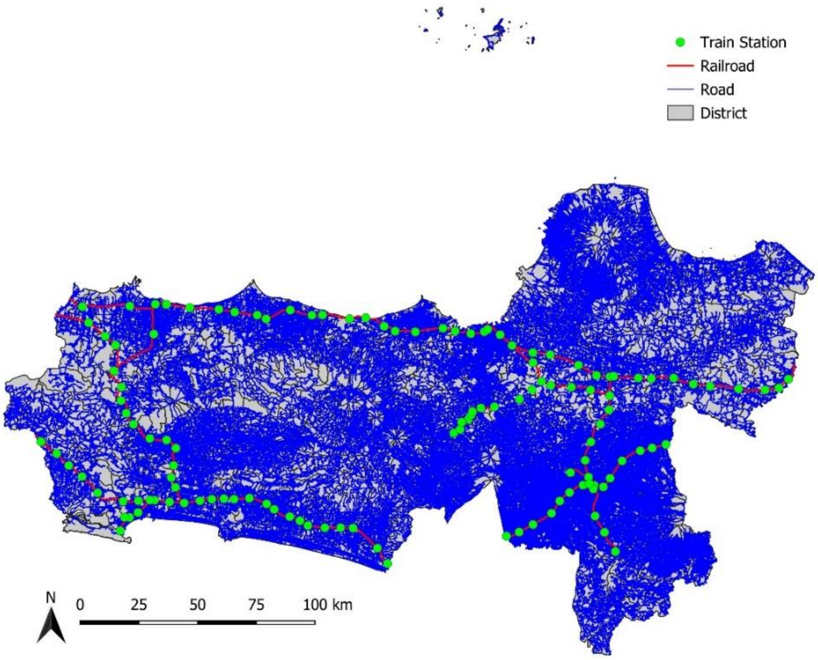


Figure 1. Map of Central Java Transportation Network

Due to the lack of detailed road geometry data, a simplified infrastructure constraint is applied. Only roads with at least four lanes or two one-way lanes are assumed to be suitable for 20-ton trucks, while other roads are served by smaller vehicles. In addition, logistics demand in each district is estimated based on population size, assuming that every 1,000 people generates a demand of 1 ton of goods. This approach reflects the general relationship between population and consumption while acknowledging that it does not capture differences in economic structure or commodity types across districts. These assumptions imply that the analysis is conducted under static and deterministic conditions and is intended for exploratory and comparative purposes rather than forecasting. Despite these limitations, the assumptions provide a transparent and consistent framework for evaluating intermodal logistics performance and for assessing how improved road–rail integration can contribute to cost reduction and enhanced regional competitiveness.

Case-Study/Scenario Design

The study uses a scenario-based case study to simulate real-world logistics conditions and determine the most efficient transportation modal routes. Two scenarios are analyzed: (1) an intermodal system combining road and rail transport, and (2) direct road transportation. The direct route serves as a cost benchmark against the potentially more economical intermodal alternative. Both scenarios start at Tanjung Mas Port, with route details shown in Figure 2. Adapting the research from Junsang et al. (2023), which optimized LNG logistics in Thailand, we adjusted our algorithm to reflect Central Java's conditions by incorporating vehicles of varying load capacities (Table 2).

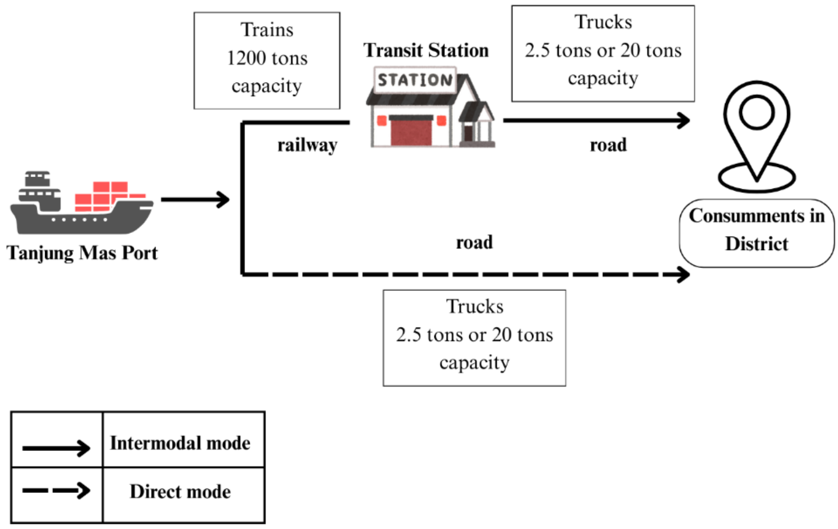


Figure 2. Proposed Distribution Network of Goods of the Case Study

(1) In the first scenario, goods from Tanjung Mas Harbor are transported by train via the railway connected to the Semarang-Tawang station to transit hubs near their final destinations. From these points, 2.5-ton or 20-ton trucks complete the last-mile delivery, depending on road accessibility. Due to the lack of detailed road width data, we assume only roads with at least four lanes or two one-way lanes can accommodate 20-ton trucks. This intermodal route is planned using the shortest, most cost-effective path within the existing road network.
(2) For the second scenario, goods are transported directly from the Tanjung Mas Port to the destination using trucks only, either with a 2.5-ton or 20-ton capacity. Comparison was made by using Dijkstra's algorithm to calculate the most cost-effective route from the port to the final destination while considering the capacities and demands by calculating the distance, fuel consumption, and fuel price as the cost.

Both scenarios use estimated demand for goods in each district based on population size, reflecting the direct relationship between the number of residents and the volume of goods needed. In this approach, we assume that every 1,000 people generates a demand of 1 ton of logistics.

Route Optimization Algorithm

Dijkstra's algorithm is one of the methods for determining the optimal path between two nodes in a graph. In our study, we define "optimal" in terms of total cost, calculated as follows,

$$Total\ cost = \sum_i \left[d \times \left\lceil \frac{D_i}{C_i} \right\rceil \times \frac{F_i}{100} \times P \right] \quad (1)$$

i: transportation mode
d: distance (in km)
D: total demand (in tons)
D_i: portion of demand transported by mode i, where $\sum_i D_i = D$
C_i: capacity of mode i (tons)
F_i: fuel consumption of the mode i (litres/100km)
P: fuel price (per litre)

This cost function serves as a partial cost approximation, focusing on fuel-based components: distance-related consumption, vehicle requirements derived from capacity and demand, and fuel prices as a proxy for variable operating expenses. It does not capture full logistics costs—such as depreciation, wages, tolls, handling fees, delay-related opportunity costs, or environmental externalities—but offers a practical, data-available proxy for comparing modal efficiency under similar regional constraints.

Cost minimization is adopted as the sole optimization objective for several reasons. First, it aligns with the study's focus on economic feasibility and provides policymakers with direct evidence on intermodal adoption. Second, model simplicity is necessary given data limitations on traffic, time windows, and commodity flows; multi-objective modeling would introduce undue complexity. Third, cost correlates strongly with time, distance, and emissions, allowing indirect optimization of these dimensions. Fourth, the approach supports regional policy priorities, notably Central Java's goal to reduce logistics costs. Finally, this single-objective framework establishes a foundation for future research into multi-criteria or dynamic logistics optimization.

Table 2. Transportation Load Capacity and Fuel Consumption

Type of transportation	Load capacity (tons)	Fuel consumption (litres/100km)
Trucks	20	15
Trucks	2.5	10
Logistic Trains	1200	100

To calculate the estimated costs, we made assumptions regarding fuel consumption for various modes of transport used in this case study. Specifically, we used the diesel fuel price in April 2025, which is 6,800 rupiah per liter. A detailed outline of the assumptions used to calculate these costs based on fuel consumption can be found in Table 2. The steps to get the most efficient are in Figure 3.

The route optimization procedure was implemented in four stages. District centroids were first identified to represent delivery destinations. Road segments suitable for 20-ton trucks were then filtered based on lane criteria (≥4 lanes or 2 one-way lanes). For direct road transport, Dijkstra's algorithm was applied to calculate the minimum cost route from the port to each district, incorporating demand and capacity ratios. In the intermodal scenario, the algorithm was used twice: first to identify the most cost-efficient railway station for each district, and then to route goods via train from the port to that station (leg 1), followed by truck delivery from the station to the final destination (leg 2). Total intermodal cost was computed as the sum of both legs.

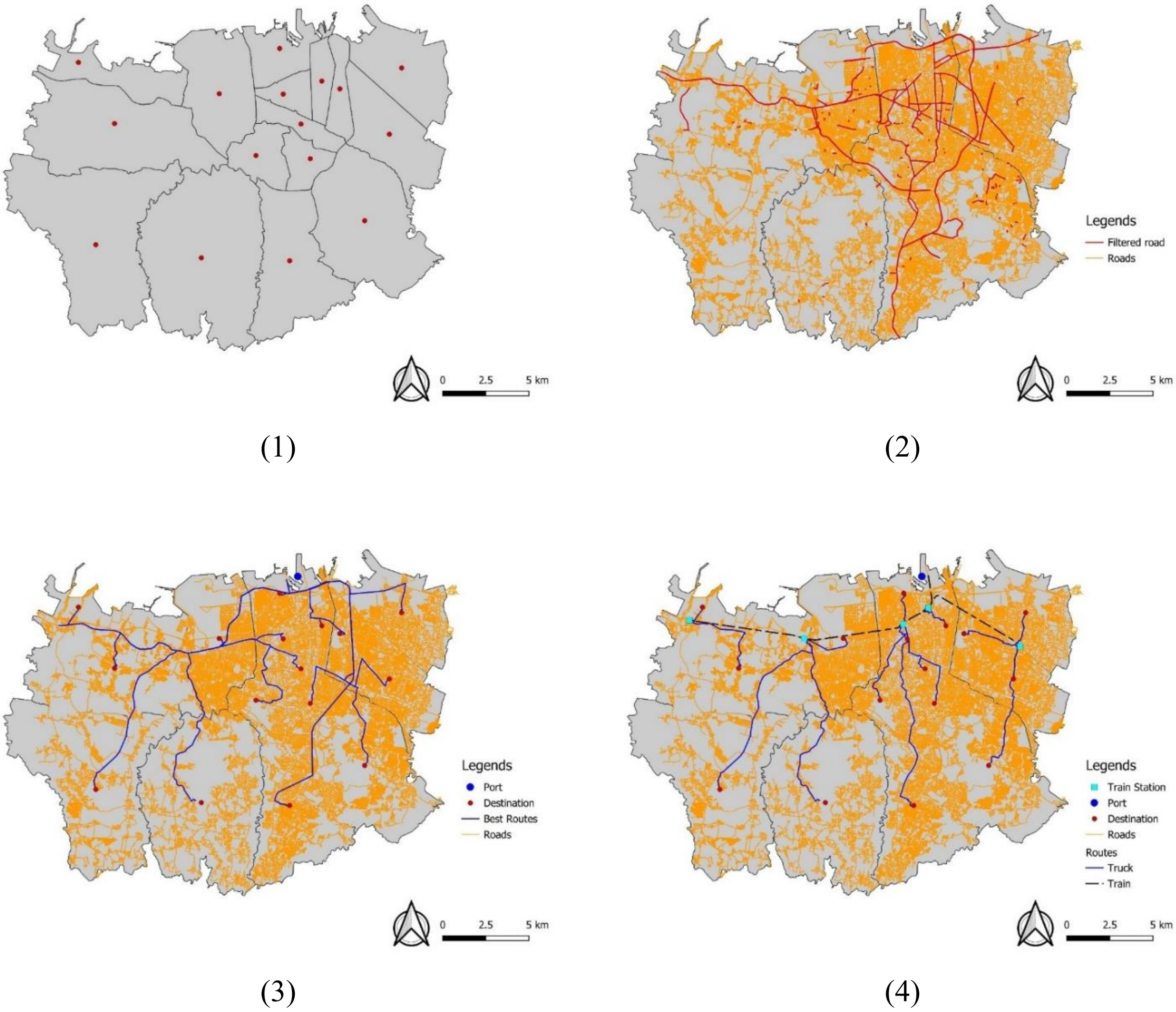


Figure 3. Step-by-Step Illustration to Calculate the Most Cost-Efficient Route

Analysis Result

The study on optimizing route and transportation mode in Central Java by utilizing Dijkstra's algorithm employs a comparative approach to determine the most suitable mode for a particular district area. The comparison between direct-single mode and intermodal transportation highlights potential strategies for reducing logistics distribution expenses. This approach ensures that the recommendations are based on established practices and customized to address the unique requirements and strengths of Central Java Province, to improve the efficiency and sustainability of its distribution logistics.

We simulated optimal transportation routes using the Dijkstra Algorithm, with Semarang City as the initial result. For example, in Ngaliyan District, which has a demand of 144 tons (rounded), the direct route from Tanjung Emas Port is 16.5 km, while the intermodal route involves 17.3 km by rail and 6.6 km by road (totaling 23.9 km). Although the direct route is shorter, it can only accommodate 2.5-ton trucks due to road limitations, requiring 58 trips. This results in 957 km traveled, consuming 96 liters of fuel, and costing IDR 652,800. In contrast, the intermodal route uses a 17.3 km train trip costing IDR 122,400, followed by eight 20-ton truck trips over 52.8 km, consuming 8 liters of fuel and costing IDR 54,400. In total, the intermodal option costs only IDR 176,800, lower than the direct route despite the longer distance.

In this section, we showed selected districts in Central Java, categorized based on their access to railway infrastructure. This distinction enables a comparative analysis of modal suitability and cost performance under varying logistical conditions.

Table 3. Example of Cost Comparison for Districts without Train Stations

Regency	District	Direct Modal Cost	Intermodal Cost
Kota Semarang	Banyumanik	129715.5	10370.88
Tegal	Adiwerna	1282583	59194.88
Brebes	Banjarharjo	1418710	72623.45
Pemalang	Ulujami	767214.3	41758.75
Pemalang	Randudongkal	1034346	61049.38
Kudus	Dawe	418113.2	47311.04
Demak	Sayung	89574.84	10806.78
Jepara	Bangsri	461966.4	52183.62
Brebes	Bantarkawung	1327150	81561.36
Tegal	Balapulang	1043163	63741.63

Note: Data processed by the author

Table 4. Example of Cost Comparison for Districts with Train Stations

Regency	District	Direct Modal Cost	Intermodal Cost
Kota Surakarta	Jebres	809755.8	34993.19
Cilacap	Kroya	1333073	65650.69
Sukoharjo	Sukoharjo	557813.2	41322.41
Grobogan	Gubug	170638.7	11703.98
Kota Tegal	Tegal Timur	782375.3	53173.19
Karanganyar	Gondangrejo	482527.4	35081.93
Boyolali	Nogosari	340473.7	34164.25
Banyumas	Kebasen	746540.1	65118.42
Banyumas	Patikraja	744608.8	63619.55
Sragen	Gemolong	246527.2	28253.56

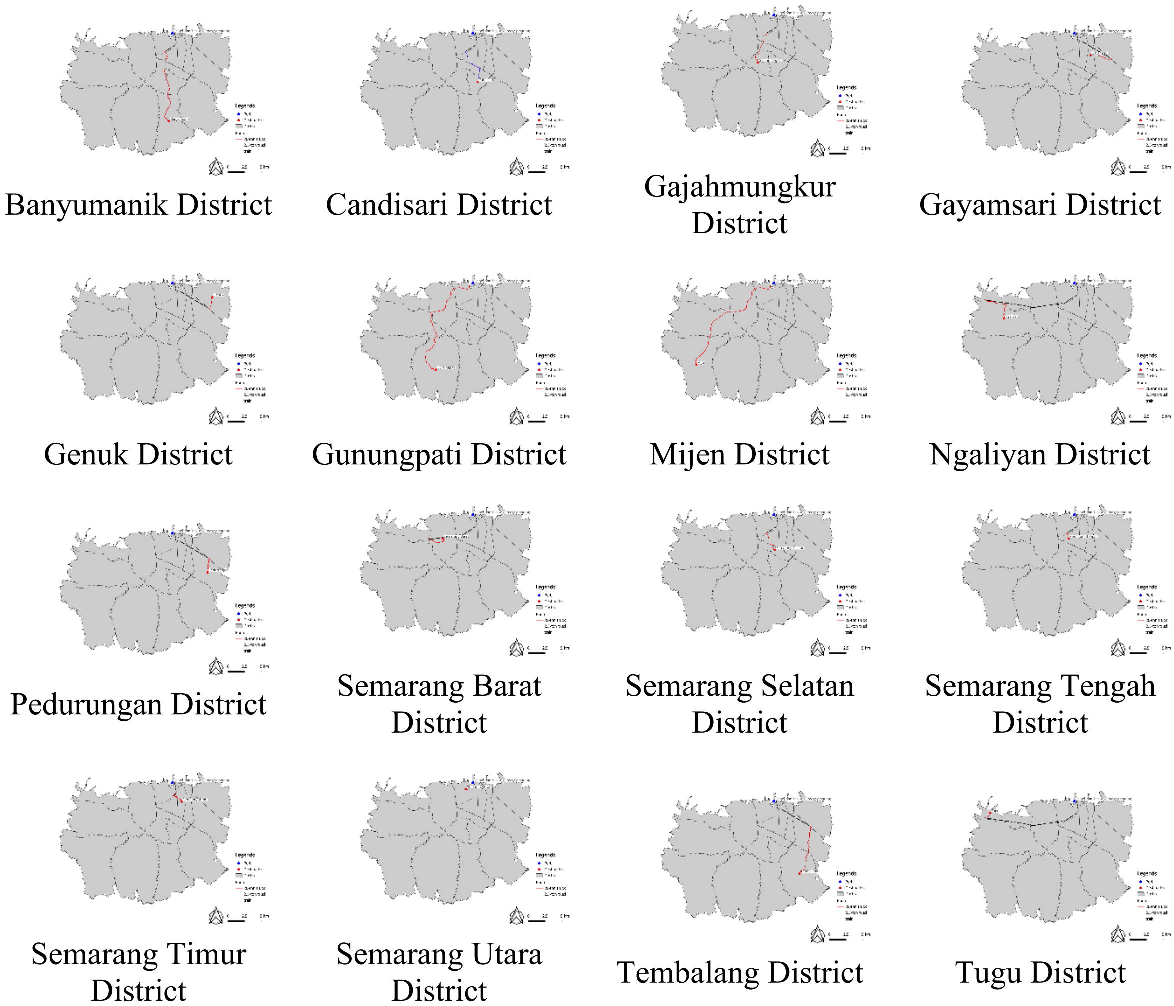
Note: Data processed by the author

The cost comparison reveals that intermodal consistently outperforms direct modal transport across districts, regardless of rail infrastructure availability. In districts with rail connections, the anticipated cost benefits of intermodal solutions are realized, thanks to access to integrated terminals and effective port-rail operations.

Conversely, an interesting observation arises in non-rail districts, such as in Jepara and Kudus, where intermodal freight also reveals a cost benefit. This indicates that the closeness to intermodal gateways (Tanjung Emas Port), along with elevated road transport expenses and effective short-haul feeder services, can compensate for the lack of direct rail access.

These findings suggest that the cost efficiency of intermodal systems is shaped not just by rail infrastructure but also by a mixture of geographic location, access to transfer hubs, and the overall effectiveness of the modal interface. Therefore, intermodal approaches can be effective, even in areas that have typically been underserved, if there is a coordinated effort in investing in first/last-mile logistics and intermodal connections.

In addition to these districts, Semarang City was included as a special case due to its strategic role as the primary port gateway (Tanjung Emas Port) and logistics hub in Central Java. As the epicenter of multimodal operations, Semarang provides a critical benchmark for evaluating the operational and economic dynamics of intermodal freight in Central Java. Each district in Semarang City has a different optimal transportation mode, as determined by the lowest cost from the Dijkstra-based calculation. This variation is influenced by factors such as distance, demand, rail access, and vehicle capacity. The key insight is that tailoring transportation modes to each district's characteristics can lead to significant cost savings. Optimizing these choices not only reduces operational expenses and improves delivery efficiency but also helps alleviate road congestion and lower carbon emissions through the use of intermodal transport.



Banyumanik District | Candisari District | Gajahmungkur District | Gayamsari District
Genuk District | Gunungpati District | Mijen District | Ngaliyan District
Pedurungan District | Semarang Barat District | Semarang Selatan District | Semarang Tengah District
Semarang Timur District | Semarang Utara District | Tembalang District | Tugu District

Figure 4. Route Visualization for Semarang Municipality

Most districts in Semarang benefit from lower logistics costs when using the intermodal approach, primarily due to rail transport's lower cost per kilometer for higher load capacity. However, this is not the universal case. In districts like Gunungpati and Mijen, the distance from railway access points makes intermodal transport less efficient, making direct road transport more cost-effective. Semarang Utara, located near Tanjung Mas Port, also favors direct trucking due to minimal travel distance. Notably, Pedurungan, as the district with the highest demand, achieves substantial cost savings with intermodal transport, highlighting the potential of combining rail and road modes for high-volume deliveries.

Table 5. Semarang Municipality Cost Estimation Result

District	Demand	Direct Mode	Direct Distance	Intermodal Mode	Intermodal Distance (train; truck)	Direct Total Cost	Intermodal Total Cost
Banyumanik	145	2.5-ton truck	20.70	Train; 2.5-ton truck	3.78; 14.22	816,577	586,644
Candisari	77	2.5-ton truck	15.32	Train; 2.5-ton truck	3.78; 7.27	322,956	178,944
Gajahmungkur	58	2.5-ton truck	16.29	Train; 2.5-ton truck	3.78; 8.19	265,928	159,310
Gayamsari	72	2.5-ton truck	8.62	Train; 20-ton truck	8.61; 5.4	169,958	80,604
Genuk	129	2.5-ton truck	10.25	Train; 20-ton truck	8.61; 2.37	362,333	75,506
Gunungpati	103	20-ton truck	20.45	Train; 20-ton truck	9.74; 12.66	125,184	143,682
Mijen	83	20-ton truck	20.44	Train; 20-ton truck	9.74; 12.64	104,223	130,675
Ngaliyan	144	2.5-ton truck	16.52	Train; 20-ton truck	17.3; 6.67	651,487	172,073
Pedurungan	199	2.5-ton truck	16.34	Train; 20-ton truck	8.61; 2.79	888,761	87,023
Semarang Barat	152	2.5-ton truck	7.59	Train; 20-ton truck	9.74; 3.13	314,820	91,727
Semarang Selatan	66	2.5-ton truck	13.24	Train; 2.5-ton truck	3.78; 4.26	243,030	103,857
Semarang Tengah	57	2.5-ton truck	11.33	Train; 20-ton truck	3.78; 1.53	177,276	30,357
Semarang Timur	69	2.5-ton truck	7.12	train, 20-ton truck	3.3; 2.91	135,617	34,296
Semarang Utara	118	20-ton truck	1.41	train, 20-ton truck	3.78; 2.22	8,619	39,290
Tembalang	194	2.5-ton truck	17.09	train, 20-ton truck	8.61; 11.61	906,400	176,943
Tugu	34	2.5-ton truck	19.21	train, 20-ton truck	17.3; 1.17	182,878	120,040

Note: Data processed by the author

Table 6. Statistical Test Result

Statistical Test	p-value
Shapiro-Wilk	0.0043
Binomial	0.0038
Wilcoxon	0.0002

Note: Data processed by the author

To evaluate whether the cost differences between intermodal and direct road transport modes are statistically significant, we conducted three tests: the Shapiro-

Wilk test, the Binomial test, and the Wilcoxon Signed-Rank test. The Shapiro-Wilk test yielded a p-value of 0.0043, indicating that the data is not normally distributed. Consequently, we applied the non-parametric Wilcoxon Signed-Rank test, which is appropriate for small sample sizes and non-normal distributions. This test produced a p-value of 0.0002, confirming a statistically significant difference between the two modes. The Binomial test also supported this finding ($p = 0.0038$), suggesting that the intermodal approach more frequently results in lower logistics costs compared to the direct road-only option. The analysis shows that adopting intermodal transport significantly reduces logistics costs across many districts in Semarang, enhancing overall supply chain efficiency and business competitiveness in Central Java. Districts like Genuk and Pedurungan experience substantial cost savings, making goods more affordable and boosting market access for producers. This improved connectivity allows peripheral areas to better integrate into domestic and global markets, which can stimulate economic activity outside the urban core. As a result, economic growth in Central Java could become more balanced and decentralized, reducing pressure on central areas and fostering more inclusive regional development.

These cost reductions have significant implications for the broader regional cost structure and economic competitiveness of Central Java. Logistics costs represent a major component of final prices for both manufactured and agricultural goods. By lowering distribution expenses, intermodal transport directly reduces the cost burden on local industries, thereby improving their profitability and enhancing their competitive position in wider markets. The comparative advantage offered by lower logistics costs can make Central Javanese products more attractive both domestically and for export, strengthening the province's role within national and global value chains.

Furthermore, intermodal logistics helps to flatten the spatial cost inequality traditionally faced by districts farther from Tanjung Emas Port. By providing a high-capacity, lower-cost alternative to long-haul trucking, rail-based intermodal systems mitigate the economic penalty of distance. This leads to a more balanced regional cost profile, which can stimulate investment and production in previously disadvantaged areas. Beyond direct transport savings, this shift also alleviates hidden economic costs associated with road congestion, infrastructure deterioration, and environmental externalities—factors that collectively strain public resources and hinder sustainable regional development.

Therefore, the transition toward intermodal logistics should be viewed not merely as a transport sector improvement, but as a strategic regional development policy. It enhances Central Java’s overall economic resilience, supports industrial scalability, and fosters a more integrated and competitive provincial economy.

Intermodal logistics distribution involves various stakeholders who impact transport development. Factors that affected the development of intermodal transport include the poor condition of infrastructure and the unequal distribution of rail stations. Enhancing the state of intermodal transport requires collaborative actions from various stakeholder groups, with particular emphasis on the responsibilities of authorities tasked with transport policy. Based on our research, we examine intermodal transportation in Central Java, which involves the Tanjung Mas port along with rail and road transport. A comprehensive matrix outlining the role of stakeholders is shown in Table 7.

Table 7. Institutional Mapping

Stakeholder	Key Role	Barrier	Recommendation	Incentive
Pelindo III (Tanjung Emas Port Authority)	Manages operations at the port, including stevedoring and warehousing activities.	• Yard congestion • Limited hinterland rail link capacity	Invest in yard automation and smart scheduling Coordinate with the rail operator for siding upgrades	• Increase throughput & fees • Build reputation
PT Kereta Api Indonesia (Freight)	Conducts rail freight operations to and from the port.	• Track capacity constraints • Scheduling conflicts with passenger services	Establish dedicated freight time slots Plan phased double-tracking	• Grow freight volume & revenue • Leverage assets
Trucking Companies (local & national)	Provide services for last-mile delivery and feeder routes.	• Regulatory permits (Over Dimension and Over Loading enforcement) • Fuel price volatility	Modernize fleet for compliance Adopt joint procurement or fuel hedging	• Expand service contracts • Optimize fleet usage
3PL / Logistics Service Providers	Coordinate shipments across multiple modes of transport and offer value-added services.	• Data integration across modes • Lack of standardized rates	Develop an interoperable digital Transportation Management System platform Establish industry pricing benchmarks	• Offer end-to-end solutions • Build client base
Central Java Provincial Government	Infrastructure planning, roads & rail-link investment	• Budget constraints • Lengthy procurement processes	Pursue Public–Private Partnership models for key freight corridors Streamline e-tendering	• Regional economic growth • Job creation
Ministry of Transportation	National transport policy, safety & standards	• Inter-agency coordination • Balancing national vs local priorities	Form intermodal task forces Create joint infrastructure plans with provinces	• Promote sustainable multimodal transport • Meet national targets
Ministry of Finance / Bappenas	Funding & fiscal policy, infrastructure financing	• Competing budget demands (health, education) • Project ROI uncertainty	Prioritize high-impact freight corridors Use blended financing	• Efficient public investment • Fiscal sustainability
Shippers (Manufacturers, Farmers)	Calculate the cargo volume and specify the delivery requirements.	• Lack of visibility on modal options • Contract inflexibility	Use digital freight marketplaces Adopt adaptive delivery contracts	• Lower logistics cost▪ Faster, more reliable delivery
End Consumers / Retailers	Receive goods, influence service standards	• Limited demand forecasting data • Price pass-through delays	Invest in joint demand planning systems Align pricing with logistics costs	• Lower prices • On-time availability
Environmental & Community Groups	Advocate on pollution, land-use, and social impacts	• Weak enforcement mechanisms • Limited technical capacity	Involved early in project planning Support training on monitoring	• Reduced emissions • Minimize disruption

Note: Table compiled by the author

Our research findings on route optimization provide a cost-effective modal for freight transportation across different districts in Central Java. However, the successful implementation of the intermodal optimization is affected by various constraints imposed by different stakeholders. The effectiveness of institutional operational and market participants relies on their ability to address the structural and procedural challenges that currently obstruct seamless multimodal coordination. The barrier matrix emphasizes the diverse and interconnected constraints that are encountered throughout the logistics ecosystem. These barriers include issues such as congestion at port and rail junctions, inefficiencies in procurement procedures, regulatory inconsistencies across various jurisdictions, and a lack of digital interoperability. Instead of being standalone issues, these obstacles are intertwined and generate friction across the entire system. For example, delays in track availability caused by scheduling conflicts with passenger rail services can undermine the cost benefits associated with rail-based routes. Likewise, a lack of comprehensive data visibility for logistics providers hinders coordination, leading to inefficiencies in both shipment consolidation and scheduling.

To shift from theoretical optimization to practical implementation, the recommendation matrix presents targeted strategies for each stakeholder. These strategies encompass practical interventions such as upgrading yard management systems at ports, establishing dedicated freight time windows on shared rail corridors, and incentivizing the renewal of fleets in the road transport sector. Moreover, institutional actors, including provincial governments and national ministries, are encouraged to streamline procurement processes, align planning across agencies, and adopt financing models that can unlock stalled infrastructure investments.

However, recommendations must be complemented by a well-designed incentive framework to ensure stakeholder alignment with system-wide efficiency objectives. Effective incentives, such as performance-linked subsidies, tax relief, digitalization support, and priority terminal access, can motivate behavioral change while mitigating individual risks. These mechanisms are essential to foster cooperation, stimulate investment, and encourage innovation across the logistics ecosystem.

Thus, the combination of barrier analysis, targeted recommendations, and aligned incentives moves the discussion beyond diagnosis toward actionable policy implementation. Successful intermodal reform requires coordinated multi-stakeholder collaboration, underpinned by data transparency, synchronized investment, and clearly defined mutual benefits. For Central Java, a region with significant geographic advantages yet persistent logistical challenges, this integrated approach is crucial for realizing a cost-efficient, resilient, and sustainable freight network.

Conclusions, Limitations, and Recommendations

Conclusions

This study confirms that intermodal logistics systems (integrating rail and road transport) offer a cost-efficient and sustainable alternative to conventional road-based freight distribution in Central Java. Through the application of Dijkstra’s algorithm on a modeled transport network, the analysis demonstrates that intermodal routes significantly reduce total logistics costs in the majority of districts, particularly those with higher demand and existing rail accessibility. Statistical validation using the

Wilcoxon Signed-Rank test (p = 0.0002) further supports the significance of these cost advantages.

Based directly on these findings, the study provides clear policy implications for the Central Java government: to enhance regional competitiveness and reduce logistics burdens on businesses, the provincial administration should prioritize strategic investments in intermodal hubs, last-mile road upgrades, and expanded rail connectivity. Such measures are expected to not only lower operational costs for shippers but also promote more balanced regional development, alleviate road congestion, and support environmental sustainability across the province.

Limitations

Despite its contributions, this study acknowledges several limitations that warrant consideration. Demand was estimated using a population-based proxy, which does not capture actual commodity flows or sector-specific logistics patterns. Infrastructure assumptions were simplified, particularly regarding road suitability for 20-ton trucks, which was based solely on lane count without accounting for pavement strength, gradient, or congestion. Cost parameters, including fuel consumption and price, were held constant, whereas real-world fluctuations could affect model accuracy. Additionally, the optimization focused exclusively on cost minimization, omitting critical factors such as delivery time, service reliability, perishability constraints, and operational scheduling challenges. The exclusion of toll road fees may also result in an underestimation of total road transport costs, particularly in corridors reliant on toll infrastructure.

Recommendations

Derived from the study’s results, the following recommendations are proposed to advance intermodal logistics in Central Java. First, intermodal transfer hubs should be developed in proximity to high-demand districts such as Tembalang and Banyumanik to facilitate efficient rail-to-road transitions. Second, key road segments serving districts dependent on direct trucking should be upgraded—through lane expansion and pavement reinforcement—to safely accommodate higher-capacity vehicles. Third, strategic investments in rail infrastructure should be prioritized to enhance connectivity for remote districts, thereby fostering regional economic integration. Finally, vehicle deployment strategies should be tailored to local infrastructure conditions, utilizing larger trucks in well-connected areas to optimize transport efficiency and reduce per-unit costs.

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