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Optimizing Multimodal Freight Transport : Railway–Airport Integration for Sustainable Logistics in Indonesia

Anisa Mahadita Candrarahayu[1], Efendhi Prih Raharjo[2], Hana Wardani Puruhita[3], I Kadek Surya Putra Adidana[4]

[1]Land Transportation and Logistics Management, Indonesian Land Transportation Polytechnic (STTD), Bekasi, [2]Traffic Engineering in Land Transportation System, Indonesian Land Transportation Polytechnic (STTD), Bekasi, [3]Building Technology and Railway Track Engineering, Indonesian Railway Polytechnic, Madiun, Indonesia, [4]Traffic Engineering in Land Transportation System, Bali Land Transportation Polytechnic, Bali

Email Address: anisa.rahayu@ptdisttd.ac.id[1], efendhisttd@gmail.com[2], hana@ppi.ac.id[3], kadek.adidana@poltradabali.ac.id[4]

Email Correspondence: anisa.rahayu@ptdisttd.ac.id[1]

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ABSTRACT

This study examined the integration of railway infrastructure with airport logistics in Indonesia to improve freight transport efficiency. The objectives were to analyze existing conditions, identify infrastructure and operational needs, assess potential demand for modal shift, and develop an integrated logistics model. A mixed-method approach was used, including cost and time analysis, gravity model, and Analytical Hierarchy Process supported by stakeholder interviews. The results showed that freight transport is still dominated by road, causing high costs, congestion, and environmental impacts. Railway integration can reduce logistics costs by 23.24% and delivery time by 44.6%, with high-potential corridors identified in major regions. Cost, time, and reliability were found to be the main decision factors. The Airport Rail Freight Integrated Hub model is proposed as a phased solution to support efficient and sustainable logistics integration, while also enhancing capacity utilization and strengthening service reliability within the national logistics system.

1. INTRODUCTION

The logistics system constitutes one of the fundamental elements supporting national economic growth, as it plays a crucial role in ensuring the smooth flow of goods, distribution efficiency, and the enhancement of industrial competitiveness. Effective logistics performance has direct implications for reducing production costs, expanding market access, and accelerating both domestic and international trade activities (Bugarčić et al., 2023). However, logistics costs in Indonesia remain relatively high compared to several other countries in Southeast Asia. This condition is influenced by the dominance of road transportation, high levels of traffic congestion, limited intermodal connectivity, and the suboptimal integration of national transport infrastructure (Syifa & Tohir, 2025) In addition, the report by (World Bank, 2021) indicates that Indonesia's logistics costs are estimated to reach approximately 23% of Gross Domestic Product (GDP), reflecting the relatively low efficiency of the national distribution system.

In the context of modern transportation development, the concept of multimodal transportation has become increasingly relevant in addressing logistics efficiency challenges. Multimodal transportation refers to a system of moving goods or passengers by utilizing more than one mode of transport in an integrated manner within a single journey chain. Each mode possesses its own comparative advantages. Rail transport is recognized for its high carrying capacity, punctuality, energy efficiency, and relatively strong safety performance. Meanwhile, airports offer advantages in terms of rapid distribution, particularly for high-value commodities, export goods, pharmaceutical products, and time-sensitive cargo (Rodrigue, 2020).

However, the integration between railway infrastructure and airports in Indonesia has thus far been predominantly oriented toward passenger services. Several major airports, such as Soekarno–Hatta International Airport, Kualanamu International Airport, Yogyakarta International Airport, and Adi Soemarmo International Airport, have already been connected to airport rail services; however, such integration has not yet been optimally directed toward supporting cargo logistics distribution through a well-planned and efficient multimodal system. As a result, logistics distribution to airports remains highly dependent on road transportation, which contributes to congestion on airport access roads, high vehicle operating costs, and uncertainty in delivery times (Prasojo et al., 2024). At the same time, demand for time-sensitive logistics services continues to increase, driven by the growth of e-commerce, exports of manufactured goods, the pharmaceutical industry, perishable commodities, and the distribution of high-value goods, thereby intensifying the need for transportation systems that are fast, reliable, and well-integrated (Rodrigue, 2020; Uprety, 2026). Consequently, the continued reliance on road transportation as the primary mode for logistics distribution not only leads to inefficiencies but also contributes to increased carbon emissions and the deterioration of road infrastructure (Aryanpur & Rogan, 2024; Shoman et al., 2023).

Many developed countries have implemented the concept of air–rail freight integration, which refers to the integration between airport cargo terminals and national or regional railway networks. This model is considered capable of improving supply chain efficiency, reducing road traffic burdens, accelerating distribution time, and enhancing national logistics competitiveness (Archetti et al., 2022; Yu & Jiang, 2024). Examples of its implementation can be found at Frankfurt Airport in Germany, which is widely recognized as a prime model of air–rail integration with dedicated rail terminals and integrated services (Wandelt & Sun, 2022), Amsterdam Airport Schiphol in the Netherlands, which is directly connected to national and international rail networks (Bruno & Cats, 2026), and Japan's airport system, including Narita, where high-speed rail integration has long supported efficient multimodal connectivity (Takebayashi, 2021). The success of these implementations indicates that rail–air freight integration can serve as a strategic solution for improving the efficiency of logistics systems, particularly along corridors with high freight volumes. Moreover, studies show that air–rail integration can reduce congestion, improve accessibility, and generate overall welfare and environmental benefits when effectively implemented (Xia & Zhang, 2017). In addition, integrated air–rail systems enable more efficient cargo handling processes and seamless transfers between modes, which are essential for enhancing logistics performance (Zhu et al., 2025).

Several previous studies have examined multimodal transport integration and logistics systems. Rodrigue, (2020) argues that intermodal integration is a key factor in improving the efficiency of global transportation systems. Yu & Jiang, (2024) showed that integrated air–rail freight systems can reduce overall transport costs through optimal modal allocation. In addition, Jiang et al., (2023) found that improving air–rail transfer processes can reduce processing times by up to 68%, thereby enhancing operational efficiency and reliability. Moreover, further optimization studies indicate cost reductions of around 0.93%–3.82% and improvements in service performance, confirming the role of air–rail integration in enhancing logistics efficiency (He & Li, 2024). Furthermore, empirical studies indicate that integrated multimodal systems can reduce transfer times, improve asset utilization, and minimize empty trips, all of which contribute to better logistics performance and lower operational inefficiencies (Bruno & Cats, 2026; Lei & Mu, 2024; Toet et al., 2025). However, most of these studies are conducted in the context of developed countries and do not fully consider the geographical characteristics, institutional settings, and infrastructure conditions in Indonesia. In addition, comprehensive studies that integrate logistics demand analysis, spatial approaches, and operational model development remain limited.

Indonesia has significant potential to develop a rail–air logistics integration model, particularly in strategic corridors that connect major airports, railway networks, and large-scale industrial zones. Potential areas include Soekarno–Hatta International Airport integrated with Cikarang Dry Port, Juanda International Airport with the Surabaya industrial region, Kualanamu International Airport with industrial zones in North Sumatra, Kertajati International Airport within the Rebana Metropolitan Area, as well as Sultan Hasanuddin International Airport connected to Makassar New Port. Developing such integrated logistics systems is expected to enhance supply chain efficiency, reduce dependency on road-based freight, and strengthen national logistics competitiveness (World Bank Group, 2026). Moreover, this development aligns with sustainable transport principles, as rail transport produces significantly lower carbon emissions per ton-kilometer compared to trucking (International Energy Agency, 2023), supporting efforts to reduce environmental impacts and promote greener logistics systems.

Based on the foregoing discussion, a clear research gap can be identified, namely the lack of comprehensive studies that integrate logistics demand analysis, potential freight demand, and the development of an operational model for rail–airport integration in Indonesia. Therefore, this study proposes an approach through the development of an Airport Rail Freight Integrated Hub model as a framework for logistics integration, linking industrial areas, dry ports, railway networks, and airport cargo terminals within a single, integrated multimodal system.

Thus, this study aims to: (1) analyze the existing conditions of logistics integration between railway infrastructure and airports; (2) identify the infrastructure and operational requirements of multimodal logistics systems; (3) assess the potential logistics demand that can be shifted to rail transport; and (4) formulate an integrated logistics development model that is aligned with the characteristics and context of Indonesia.

2. METHODS

This study employs a mixed-methods approach, integrating both quantitative and qualitative techniques to comprehensively analyze the development of an integrated rail–air logistics system in Indonesia. The combination of methods enables a more robust understanding of spatial, operational, and strategic aspects of logistics integration.

Research Design

The research framework consists of four main stages: (1) identification of key variables and indicators, (2) data collection, (3) spatial and quantitative analysis, and (4) formulation of development strategies. A bibliometric approach using VOSviewer is incorporated at the initial stage to systematically identify relevant variables and indicators from previous studies.

Bibliometric Analysis using VOSviewer

A bibliometric analysis is conducted using VOSviewer to identify key variables, research trends, and dominant themes related to multimodal logistics integration and air–rail freight systems. Scientific publications are collected from indexed databases such as Scopus and Google Scholar (last 5 years). The analysis includes :

The analysis includes :

1. Co-occurrence analysis of keywords to identify dominant variables
2. Network visualization to map relationships among variables.
3. Cluster analysis to group indicators into major dimensions such as infrastructure, operations, economy, and sustainability.

The results of this analysis are used to define the criteria and indicators applied in subsequent AHP and spatial analyses, ensuring that the study is grounded in current scientific evidence.

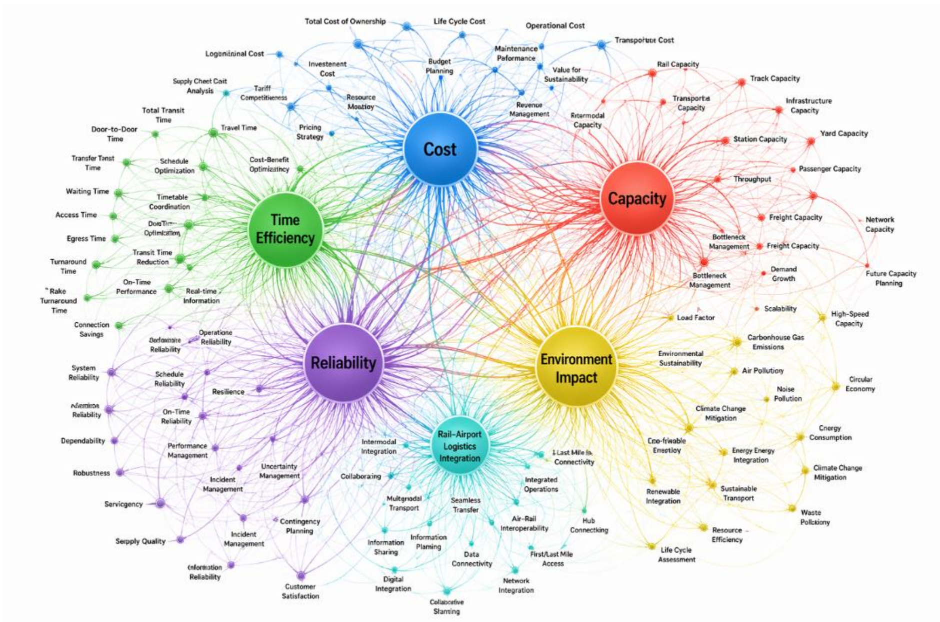

Figure 1. VosViewer Result

Table 1. Mapping of Literatures on Railway–Airport Logistics Integration

Number article	Cost	Time Efficiency	Capacity	Reliability	Environmental Impact	Main Topic
1	✓	✓	✓	✓	✓	Air-Rail Integration
2	✓	✓	-	✓	✓	Airport Access
3	-	✓	✓	✓	-	Schedule Optimization
4	✓	✓	✓	-	✓	Multimodal Transport
5	✓	✓	-	✓	-	Logistics Efficiency
6	-	✓	✓	✓	✓	Sustainable Transport
7	✓	-	✓	✓	✓	Intermodal System
8	✓	✓	-	-	✓	Airport Connectivity
9	-	✓	✓	✓	-	Rail-Air Network
....	....	....	....	....	....	....
70	✓	-	✓	✓	-	Integrated System

Data Collection Technique

The data collection process includes:

1. Secondary Data
   a. Cargo volume data from major airports
   b. Existing railway network data and planned railway development projects
   c. Data on industrial zones and logistics distribution centers
   d. National logistics and transportation policy documents
2. Primary Data
   a. Interviews with key stakeholders, including airport operators, railway operators, logistics companies, and regulatory authorities
   b. Questionnaires distributed to logistics service users to capture preferences, constraints, and demand characteristics

Data Analysis Technique

1. Geographic Information System (GIS) Analysis

   GIS analysis is utilized to evaluate spatial connectivity, accessibility, travel distances, and service coverage between airports, railway networks, and industrial zones. This analysis helps identify potential logistics corridors and integration nodes.
2. Analytical Hierarchy Process (AHP)

   The AHP method is employed to determine the priority of integration needs based on criteria derived from the VOSviewer analysis. The criteria include:
   a. Cost
   b. Time Efficiency
   c. Capacity
   d. Reliability
   e. Environment Impact

3. Gravity Model

The Gravity Model is applied to estimate the potential flow of goods between industrial areas and airports :

$$Tij = \frac{Pi \ x \ Aj}{dij^2} \qquad (1)$$

Where:

Tij : freight flow potential between region *i* and region *j*

Pi : production potential of origin region *i*

Aj : attraction factor of destination region *j*

dij : distance between region *i* and region *j*

This model is used to identify high-potential logistics corridors for rail–air integration.

4. SWOT Analysis

SWOT analysis is used in this study to formulate development strategies and policy recommendations for the integrated rail–air logistics system. This method evaluates internal factors (strengths and weaknesses) and external factors (opportunities and threats) affecting logistics integration.

The analysis begins with the identification of relevant factors based on literature review, stakeholder interviews, and previous analytical results, including GIS, AHP, and the Gravity Model. These factors are then classified into a SWOT matrix to examine their interactions.

Based on this matrix, four types of strategies are developed: SO (leveraging strengths to exploit opportunities), WO (overcoming weaknesses using opportunities), ST (using strengths to mitigate threats), and WT (minimizing weaknesses and avoiding threats). The results are used to provide strategic recommendations for developing an efficient and sustainable multimodal logistics system.

3. RESULTS

Exsisting Condition Analysis

The results indicate that airport freight distribution in Indonesia remains highly dependent on road-based trucking systems. Across the selected case study locations—Soekarno-Hatta, Juanda, Kualanamu, Kertajati, and Hasanuddin Airports—more than 85% of cargo movement from industrial zones to airport terminals is transported by trucks. This condition creates several structural inefficiencies:

1. High congestion levels on airport access corridors;
2. Uncertain delivery time reliability;
3. High logistics operating costs;
4. Excessive fuel consumption;
5. Increased greenhouse gas emissions;
6. Limited multimodal transfer facilities.

These findings are consistent with the (World Bank Group, 2026), which reported that excessive road dependency in freight systems significantly increases national logistics costs in developing countries.

Furthermore, although airport rail links have been introduced in several Indonesian cities, these services are designed almost exclusively for passenger mobility rather than freight integration. This condition creates several structural inefficiencies:

Quantitatice Results

1. Logistics Demand Assessment

The gravity model was employed to estimate freight interaction between industrial zones and airports.

Cikarang – Soekarno – Hatta

a. Industrial Output Index : 950
b. Airport attractiveness : 800
c. Distance : 45 km

Tij : 375,31

The result demonstrates a very high freight attraction potential, indicating that the Cikarang–Soekarno Hatta corridor is highly suitable for rail-air cargo integration.

Table 2. Priority Freight Corridors

Corridor	Gravity Score	Priority
Cikarang – Soekarno-Hatta	375.31	Very High
Rebana – Kertajati	341.27	Very High
SIER – Juanda	296.42	High
Medan Industrial Zone – Kualanamu	281.15	High
Makassar Port Zone – Hasanuddin	220.08	Medium

Cost Efficiency Analysis

A comparative logistics cost analysis was conducted between trucking and railway freight systems.

$$E=C_t-C_r \qquad (2)$$

Where:

E : cost efficency
Ct : trucking cost
Cr : railway freight cost

Table 3. Cost per Container of Modes

Mode	Cost per Container (IDR)
Trucking	1,850,000
Railway	1,420,000

Savings: 430,000 IDR/container

Equivalent to 23.24% lower logistics cost.

This result supports Rodrigue (2020), who noted that rail freight becomes more economical for medium-distance cargo corridors with high shipment frequency.

Travel Time Performance

$$T = \frac{s}{v} \quad (3)$$

Where:

T : travel time

s : distance

v : average speed

Table 4. Average Time of Modes

Mode	Average Time
Truck	130 min
Rail Freight	72 min

Travel time reduction reached 44.6%**,** largely due to dedicated rail movement unaffected by urban congestion.

AHP Priority Analysis

The Analytical Hierarchy Process (AHP) was used to identify the most critical decision factors for logistics integration. With criteria :

1. Cost
2. Time
3. Reliability
4. Capacity
5. Environmental impact

Table 5. Final Wheight of Criteria

Criteria	Weight
Cost	0.38
Time	0.27
Reliability	0.19
Capacity	0.10
Environment	0.06

The consistency ratio (CR) was below 0.10, indicating acceptable model consistency. The results show that logistics operators prioritize **cost and delivery time** over environmental considerations.

Qualitative Findings

Semi-structured interviews were conducted with regulators, airport operators, railway companies, freight forwarders, and manufacturers. Main Themes Identified :

1. Infrastructure Gap
   Stakeholders emphasized the absence of dedicated rail freight terminals directly connected to airport cargo zones.
2. Digital Fragmentation

Cargo booking, customs clearance, trucking dispatch, and rail scheduling remain separated across multiple systems.

3. Need for Policy Incentives
   Operators suggested tariff incentives, public-private partnership financing, and simplified multimodal regulation.
4. Reliability Requirement
   Manufacturing exporters require guaranteed shipment schedules aligned with aircraft departure slots.

SWOT Analysis and Proporsed Development Model

Table 6. SWOT Analysis

Strengths	**Weaknesses**
Existing rail network	Limited freight terminals
Large domestic market	Institutional fragmentation
Growing air cargo demand	Initial capital intensity
Opportunities	**Threats**
E-commerce growth	Trucking market resistance
Export expansion	Land acquisition issues
Green logistics policy	Regulatory delays

Airport Rail Freight Integrated Hub (ARFIH) The proposed model integrates industrial production zones, inland terminals, rail freight corridors, and airport cargo terminals.
Logistics Flow:

Factory → Dry Port → Freight Rail → Airport Cargo Terminal → Aircraft

Core Component :

1. Inland consolidation terminal
2. Dedicated rail spur line
3. Automated cargo transfer yard
4. Cold chain logistics center
5. Customs smart gate system
6. Real-time cargo visibility platform

Implementation Phasing

The development is implemented in three sequential phases to ensure gradual and sustainable integration. Phase I (2026–2030) focuses on pilot corridors, namely Cikarang–Soekarno-Hatta and Rebana–Kertajati, to test operational feasibility, coordination mechanisms, and initial system performance. Phase II (2030–2035) expands the system to major airports such as Juanda, Kualanamu, and Hasanuddin, with the objective of increasing network coverage, improving connectivity, and enhancing logistics capacity across regions. Finally, Phase III (2035–2045) aims to achieve full national integration of the rail–air freight network, creating a seamless, efficient, and sustainable logistics system that supports long-term economic growth and intermodal transport development.

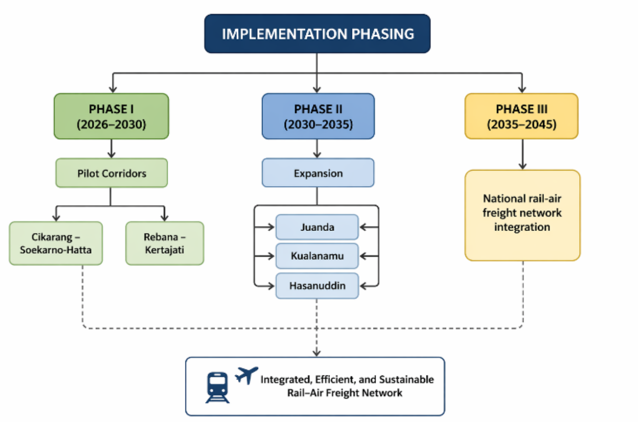

Figure 2. Phased Implementation Plan for Railway – Airport Freight Integration

4. DISCUSSION

The findings confirm that rail–air freight integration can significantly reduce logistics costs, improve punctuality, and lower emissions. These results are consistent with recent studies. For example, Zhao et al. (2023) reported that rail–airport connectivity reduces logistics costs by 18–25% in Asian corridors. In addition, research by He & Li, (2024) shows that optimizing air–rail integration improves scheduling efficiency and service reliability . Furthermore, studies on intermodal logistics indicate that rail transport contributes to cost efficiency and environmental sustainability compared to road-based systems (Abu-Aisha et al., 2024).

From a broader perspective, integrated logistics systems have been proven to enhance overall transport efficiency and airport performance, particularly when supported by rail connectivity (Fernández et al., 2022). Moreover, global evidence highlights that shifting freight to rail reduces emissions while improving capacity and operational performance (World Bank Group, 2025).

This chapter demonstrates that integrated railway-airport logistics systems are economically feasible, operationally beneficial, and environmentally sustainable.

Key findings include:

1. Rail freight reduces logistics cost by 23.24%;
2. Delivery time decreases by 44.6%;
3. High-demand corridors exist around Jakarta and West Java;
4. Cost and time are dominant stakeholder priorities;
5. The ARFIH model is suitable for phased implementation in Indonesia.

5. CONCLUSION

This study confirms that integrated railway–airport logistics is a strategic approach to improving national freight efficiency, reducing logistics costs, and strengthening economic competitiveness in Indonesia. Currently, airport freight distribution remains highly dependent on road transport, leading to congestion, high operating costs, delivery uncertainty, and environmental impacts. The findings also show that integration between railway infrastructure and airports is still limited and predominantly passenger-oriented, indicating a significant opportunity to develop multimodal freight systems supported by key infrastructure and better operational coordination.

Quantitative analysis demonstrates that railway freight connectivity can reduce logistics costs by approximately 23.24% and shorten delivery time by 44.6% compared to road transport. High-potential corridors have been identified, particularly Cikarang–Soekarno-Hatta, Rebana–Kertajati, Surabaya–Juanda, and Medan–Kualanamu. In addition, the AHP results reveal that cost, delivery time, and reliability are the most influential factors in stakeholder decision-making, while interviews highlight the importance of intermodal terminals, digital integration, regulatory simplification, and investment support.

Based on these findings, the Airport Rail Freight Integrated Hub (ARFIH) model is proposed as the most suitable framework for Indonesia. This model integrates industrial zones, dry ports, rail freight terminals, and airport cargo facilities into a unified logistics system and can be implemented in phases. Overall, railway–airport logistics integration represents not only a transport solution but also a long-term strategy to develop a more efficient, reliable, and sustainable national logistics system.

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