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Optimization of Built Environment and Structural Configuration for Rail-Airport Intermodal Transfer Systems: Evidence from Adi Soemarmo Airport, Surakarta

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ABSTRACT

This study aims to evaluate the level of multimodal transport integration between rail services and airport facilities using the Intermodal Seamless Mobility (ISM) approach at Bandar Udara Adi Soemarmo, Indonesia. A quantitative descriptive case study method was employed through field observations and direct measurement of three key indicators: Walking Distance (WD), Transfer Time (TT), and Baggage Friction Index (BFI). These indicators were normalized and synthesized into the Intermodal Seamless Mobility Index (ISMI) to assess the quality of passenger transfer connectivity. The results indicate a Walking Distance of 146 m, Transfer Time of 4 min, and BFI of 0.547. Based on the weighted indicator model, the calculated ISMI value was 0.6697, which falls within the Good Seamless category. This finding suggests that passenger transfer from the railway station to the airport terminal is relatively efficient, convenient, and functionally integrated. However, further improvements are required to achieve the Highly Seamless category, particularly through baggage-handling facilities enhancement, additional travelators, improved wayfinding systems, and stronger intermodal information integration.

1. INTRODUCTION

The development of modern transport systems requires intermodal integration that not only focuses on vehicle movement efficiency but also emphasizes comprehensive passenger mobility, including the transfer of passengers together with their baggage. The concept of multimodal transportation has become a major approach in contemporary transport and logistics systems because it connects various transport modes within a single integrated travel chain, thereby improving time efficiency, reducing costs, and lowering carbon emissions (Rodrigue et al., 2020; Macharis & Bontekoning, 2004).

From a Supply Chain Management perspective, transportation is a critical element that determines the smooth flow of goods, information, and services from upstream to downstream activities. Fragmented transport systems may increase logistics costs, waiting time, and overall supply chain inefficiency (Christopher, 2016). Therefore, integration between railway services and airport facilities is essential to support efficient, responsive, and sustainable logistics systems, particularly under increasing demand for reliable passenger mobility and synchronized service networks (Chopra & Meindl, 2019).

Beyond logistics considerations, recent transport studies highlight the importance of Intermodal Seamless Mobility (ISM), defined as a mobility system that enables easy, fast, and barrier-free modal transfers for users. ISM encompasses not only physical infrastructure integration, but also passenger comfort, navigational clarity, spatial accessibility, and the convenience of carrying baggage between transport modes (Givoni & Banister, 2010). Efficient interchange design is also recognized as a major determinant of public transport competitiveness and user satisfaction (Vuchic, 2005).

One of the key dimensions of ISM is baggage transfer convenience, referring to the extent to which passengers can move from a railway station to an airport terminal without significant obstacles. Such barriers may include excessive walking distance, level changes, inadequate supporting facilities such as lifts or moving walkways, and insufficient wayfinding systems. Previous studies indicate that the quality of intermodal connectivity is strongly influenced by infrastructure design that simultaneously accommodates pedestrian and baggage movement (Hine & Scott, 2000). Passenger perception research further confirms that walking effort and transfer inconvenience significantly reduce perceived service quality (Wardman, 2004).

At Bandar Udara Adi Soemarmo, Surakarta, Indonesia, the integration of rail and airport transport services has strategic potential to support regional mobility in Central Java. The airport rail service has improved passenger accessibility and travel efficiency compared with road-based transport. However, from the ISM perspective, there are indications that passenger transfer convenience—particularly for travellers carrying baggage from the railway station to the airport terminal—has not yet been fully optimized. This condition can be identified through technical indicators such as walking distance, transfer time, and baggage friction caused by limited supporting facilities. In transport literature, such a condition reflects a seamlessness gap, namely the discrepancy between infrastructure integration and actual user experience (Preston, 2012). Similar studies emphasize that successful airport intramodality depends not only on infrastructure provision but also on service continuity and user-oriented station design (de Neufville & Odoni, 2013).

Based on these conditions, a more comprehensive analysis is required regarding multimodal rail–airport transport management, not only in terms of logistics and supply chain efficiency but also from the perspective of Intermodal Seamless Mobility (ISM). Accordingly, this study aims to analyse the multimodal rail–airport transport management system, evaluate its integration within logistics and supply chain operations, measure ISM performance using Walking Distance (WD), Transfer Time (TT), and Baggage Friction Index (BFI) indicators, identify key integration barriers, and formulate recommendations to enhance multimodal transport performance.

2. METHODS

Research Type and Approach

This study employed a quantitative–descriptive approach using a case study research design focusing on the rail–airport multimodal transportation system at Adi Soemarmo International Airport, Surakarta, Indonesia. The quantitative approach was applied to measure the level of Intermodal Seamless Mobility (ISM) through numerical indicators, namely Walking Distance (WD)**,** Transfer Time (TT), and the Baggage Friction Index (BFI)**.** Meanwhile, the descriptive approach was used to examine the existing conditions of the integrated transportation system and its associated supply chain.

Research Location and Object

a. Research Location: The study was conducted at the following locations: the airport railway station (rail access to the airport), the connecting pedestrian pathway, and the passenger terminal of Adi Soemarmo International Airport.
b. Research Object: The objects of this study included: the rail–airport multimodal transportation system, passenger transfer flows, connectivity infrastructure (such as walkways, signage, and terminal access), as well as the logistics system and passenger baggage movement.

Research Variables and Indicators

The principal variable examined in this study was Intermodal Seamless Mobility (ISM)**.**

Table 1. Intermodal Seamless Mobility (ISM)

No	Variable	Indicator	Symbol	Unit
1	Ease of transfer accessibility	Walking Distance	WD	meter
2	Transfer time efficiency	Transfer Time	TT	minute
3	Baggage-related constraints	Baggage Friction Index	BFI	index
4	Seamless mobility level	ISMI	ISMI	score

Operational Definition of Variables

a. Walking Distance (WD): The actual distance travelled by passengers from the train arrival point to the entrance of the airport terminal.
b. Transfer Time (TT): The total transfer time from the train to the airport terminal, including walking time, ascending or descending access facilities, and wayfinding/orientation time.
c. Baggage Friction Index (BFI): An index representing the level of difficulty experienced by passengers when carrying baggage during the transfer process.
d. The BFI was determined based on the following factors: walking distance (WD), physical barriers (such as stairs and slopes), and the availability of supporting assistance facilities (Formula 1).

$$BFI = \frac{WD\ x\ Sf\ x\ Oc}{Af} \qquad (1)$$

Types and Sources of Data

a. Primary Data: Direct measurement of Walking Distance (WD) using measuring instruments and GPS tracking; measurement of Transfer Time (TT) using a stopwatch; observation of facility conditions; and passenger surveys using a Likert scale (1–5) to assess comfort levels.
b. Secondary Data: Operational data of the airport rail service; airport terminal layout plans; transportation planning documents; and scientific literature, including journals and transportation-related books.

Data Collection Techniques

a. Field Observation: Observing passenger transfer routes and identifying physical barriers along the transfer path.
b. Direct Measurement: WD was measured using measuring devices and GPS tracking, while TT was recorded using a stopwatch based on several travel samples.
c. Questionnaire Survey: User assessments regarding transfer comfort, ease of carrying baggage, and the quality of facilities.
d. Documentation: Pedestrian pathway maps and photographs of connectivity infrastructure.

Data Analysis Techniques

a. Quantitative Descriptive Analysis: Applied to calculate the average values of WD, TT, and BFI, as well as to describe the existing conditions of the transportation system.
b. Calculation of the Baggage Friction Index (BFI): Conducted using Formula (1). The results were classified as follows: 0–1: Very comfortable; 1–2: Comfortable; 2–3.5: Moderately difficult; > 3.5: Very difficult

Intermodal Seamless Mobility Index (ISMI)

$ISMI = \omega_1(TT^{-1}) + \omega_2(WD^{-1}) + \omega_3(BFI^{-1})$

Weighting Scheme (Example): TT = 0.4; WD = 0.3; BFI = 0.3

Gap Analysis:

A gap analysis was conducted by comparing the existing conditions with the ideal standards of Intermodal Seamless Mobility (ISM). The benchmark standards used in this study were as follows:

a. Ideal Walking Distance (WD): < 100–300 m
b. Ideal Transfer Time (TT): < 5–10 minutes
c. Ideal Baggage Friction Index (BFI): < 1.5

Research Flow

a. Identification of the rail–airport multimodal transportation system.
b. Measurement of WD, TT, and BFI.
c. Quantitative data processing.
d. Calculation of the Intermodal Seamless Mobility Index (ISMI).
e. Gap analysis against the established ISM standards.
f. Formulation of strategies for system improvement.

Research Output

a. The ISMI value of the rail–airport integration system.
b. The level of passenger transfer efficiency.
c. The degree of baggage handling difficulty (BFI).
d. Recommendations for improving seamless mobility.
e. Strategies for multimodal transportation integration based on supply chain principles.

3. RESULTS

Overview of the Multimodal Transportation System

a. The rail–airport multimodal transportation system within the study area demonstrates physical integration between the airport railway service and the passenger terminal of Adi Soemarmo International Airport. This integration is intended to enhance passenger accessibility to and from the airport while simultaneously supporting the efficiency of the regional transportation system.
b. However, based on field observations, the existing integration remains largely concentrated on basic infrastructure aspects. Meanwhile, the dimensions of Intermodal Seamless Mobility

(ISM)—including passenger comfort, ease of baggage handling, and transfer time efficiency—still require significant improvement.

Figure 1. Layout Plan and Existing Condition of the Connecting Corridor between the Railway Station and the Airport

Walking Distance (WD) Measurement Results

a. The measurement results indicate that the passenger transfer distance from the train arrival point to the airport terminal varies as follows:

Table 2. Variation of Passenger Transfer Distance

No	Measurement Point	Distance (m)
1	Station → connecting corridor	120 m
2	Corridor → airport terminal entrance	7 m
3	Airport terminal entrance → check-in area	19 m
4	Average total Walking Distance (WD)	146 m

b. Interpretation: The measured Walking Distance (WD) of 146 meters, when compared to the ISM standard (100–300 meters), falls within the "good/comfortable" category**.** This indicates that the connectivity between the railway station and the airport terminal is generally well-established, thereby supporting the concept of Intermodal Seamless Mobility through relatively fast and convenient passenger transfers.

Transfer Time (TT) Measurement Results

a. Transfer time measurements were conducted across several passenger travel samples.

Table 3. Passenger Transfer Time

No	Component	Time (minutes)
1	Walking time	2,4 minutes
2	Vertical movement (escalator)	0,6 minutes
3	Orientation (wayfinding)	0,2 minutes

4	Waiting/interaction	0,8 minutes
5	Average total Transfer Time (TT)	4.0 minutes

b. Interpretation: The Transfer Time (TT) value of 4 minutes, when compared to the ISM standard (< 5 minutes), is classified as "very good / highly seamless." This indicates an efficient level of intermodal connectivity between transport modes. The result reflects a well-optimized transfer pathway characterized by short distances, direct access routes, minimal physical barriers, clear signage, and smooth passenger flow, all of which strongly support the implementation of Intermodal Seamless Mobility**.**

Baggage Friction Index (BFI) Calculation Results

The calculation was conducted using the following parameters:

a. WD = 146 m
b. Slope factor (Sf) = 1.1 (presence of elevation changes without ramp)
c. Obstacle coefficient (Oc) = 1.1 (normal pedestrian flow with several doors)
d. Assistance factor (Af) = 1.3 (availability of trolleys and escalators)
Result:

$$BFI = \frac{146\ x\ 1{,}1\ x\ 1{,}1}{1{,}3} \quad (2)$$

$$BFI = 135{,}9 \quad (3)$$

After normalization into a 0–5 scale, the BFI normalized value is approximately 0.547**.** Based on the calculation results, using a Walking Distance of 146 meters, Slope Factor of 1.1, Obstacle Coefficient of 1.1, and Assistance Factor of 1.3, the Baggage Friction Index (BFI) is obtained as 135.90. This value indicates that the level of difficulty experienced by passengers in carrying baggage from the railway station to the airport terminal falls within a moderate category and remains within an acceptable tolerance level.

This finding suggests that the passenger transfer process is generally functioning well, although it has not yet reached an optimal condition. Several factors still contribute to passenger mobility friction, including elevation changes via escalators, interaction with pedestrian flows, the need to manoeuvre luggage at certain points along the corridor, and the suboptimal provision of supporting facilities.

From an operational perspective, the BFI value of 135.90 indicates that the multimodal connectivity system at Adi Soemarmo International Airport is already sufficiently supportive of passenger mobility with baggage, but still offers opportunities for improvement to achieve a higher level of comfort. Enhancements may include more luggage-friendly vertical circulation systems, additional trolley availability, optimization of travelators, and simplification of transfer pathways.

Overall, the BFI indicator confirms that the rail–airport integration system is functioning effectively; however, the user experience quality can still be improved to fully achieve the concept of highly seamless mobility**.**

Intermodal Seamless Mobility Index (ISMI)

Table 4. Normalized Values of TT, WD, and BFI

No	Indicator	Normalized Value
1	TT	0,708

2	WD	0,733
3	BFI	0,547

Intermodal Seamless Mobility Index (ISMI) Result:

ISMI = (0,708 x 0,3) + (0,733 x 0,4) + (0,547 x 0,3)

ISMI = 0,2124 + 0,2932 + 0,1641 = 0,6697

The Intermodal Seamless Mobility Index (ISMI) value of 0.6697 falls within the "Good Seamless" category (0.65–0.80). This indicates that the passenger transfer system from the railway mode to the airport terminal at Adi Soemarmo International Airport has performed well, with relatively efficient and comfortable mobility conditions for users.

Discussion of Multimodal System Integration

Based on the normalized values of Walking Distance (WD)**,** Transfer Time (TT)**, and** Baggage Friction Index (BFI), the resulting Intermodal Seamless Mobility Index (ISMI) is 0.6697 (or 67 on a 100-point scale). This value confirms that the passenger transfer system between the railway station and the airport terminal is categorized as Good Seamless, indicating a well-functioning, efficient, and relatively comfortable intermodal connection. This result suggests that the physical integration between the airport rail station and the passenger terminal has successfully established functional intermodal connectivity. Passengers are able to transfer between modes within a relatively short time, through clearly defined pathways, and with an acceptable level of physical and operational barriers. Such conditions represent a key requirement in modern multimodal transportation systems, where performance is not only determined by infrastructure availability but also by the ease of user mobility.

From the Walking Distance (WD) perspective, the measured distance of 146 meters is considered relatively ideal for intermodal transfer facilities. This distance remains within a comfortable walking range and does not impose excessive physical burden on most passengers. In general, shorter transfer distances contribute directly to higher comfort levels and improved efficiency in integrated transport systems. In terms of Transfer Time (TT), the recorded value of 4 minutes demonstrates excellent performance. This reflects effective intermodal design in terms of station layout, terminal accessibility, and smooth passenger flow. In airport transport systems, short transfer times are critical as they directly influence travel reliability, reduce passenger stress, and enhance service quality. The Baggage Friction Index (BFI) indicates that, although the system performs adequately, there are still aspects of passenger convenience related to baggage handling that require improvement. Factors such as vertical level changes, escalator access points, directional shifts in pathways, and limited baggage assistance facilities may still affect the overall passenger experience, particularly for elderly users, families, and passengers with large luggage.

Overall, the ISMI value of 0.6697 confirms that multimodal integration at Adi Soemarmo International Airport is on a positive trajectory. The system already supports the concept of seamless mobility, characterized by practical and efficient intermodal transfers. However, to achieve the "Highly Seamless" category, further improvements are required, such as additional travelators, better accessibility of baggage trolleys, enhanced wayfinding systems, and optimization of pedestrian corridor design.

From a transportation management and supply chain perspective, strong rail–airport integration provides strategic benefits, including improved regional accessibility, increased passenger flow efficiency, reduced dependence on private vehicles, and enhanced regional mobility performance. Therefore, the multimodal system at Adi Soemarmo Airport can be considered a potential model for integrated transport development in regional airports across Indonesia.

Supply Chain Impact Analysis

From a supply chain perspective (Christopher, 2016), the current condition leads to: Increased indirect transfer costs (time and passenger energy expenditure); Reduced efficiency in passenger and baggage distribution flow; Limited potential of the airport as a multimodal logistics hub

Gap Analysis (Existing vs Ideal Conditions)

Table 5. Gap Analysis of WD, TT, BFI, and ISMI

No	Indicator	Existing	Ideal Standard	Gap	Status
1	WD	146 m	< 150 m	Within range (no critical gap)	Good / Compliant
2	TT	4 minutes	< 5 minutes	Minimal gap (highly efficient)	Very Good / Highly Seamless
3	BFI	0,547	< 1	Low gap	Moderate–Good
4	ISMI	0.6697	> 0.8 (Highly Seamless)	0.1303 below target	Good Seamless (not yet optimal)

Interpretation

a. Walking Distance (WD)
The value of 146 meters is below the ideal threshold of 150 meters. This indicates that the intermodal transfer corridor is relatively short and comfortable for passengers, supporting efficient pedestrian movement between modes.

b. Transfer Time (TT)
The value of 4 minutes is faster than the ideal benchmark of 5 minutes. This reflects a highly efficient intermodal connection with smooth passenger flow and minimal delay during transfer activities.

c. Baggage Friction Index (BFI)
The value of 0.547 is below the ideal threshold of 1.00, indicating that passengers experience relatively low difficulty in handling luggage, with no significant physical or operational barriers.

Based on the Gap Analysis results, all main indicators demonstrate that the existing conditions of the passenger transfer system from the railway station to the airport terminal at Adi Soemarmo International Airport have met the ideal standards of Intermodal Seamless Mobility. The Walking Distance of 146 meters is within the acceptable threshold of 150 meters, the Transfer Time of 4 minutes is faster than the 5-minute benchmark, and the Baggage Friction Index of 0.547 is also better than the ideal limit of 1.00. Therefore, the multimodal integration system at the study location can be categorized as very good, with only a minimal gap from the ideal condition.

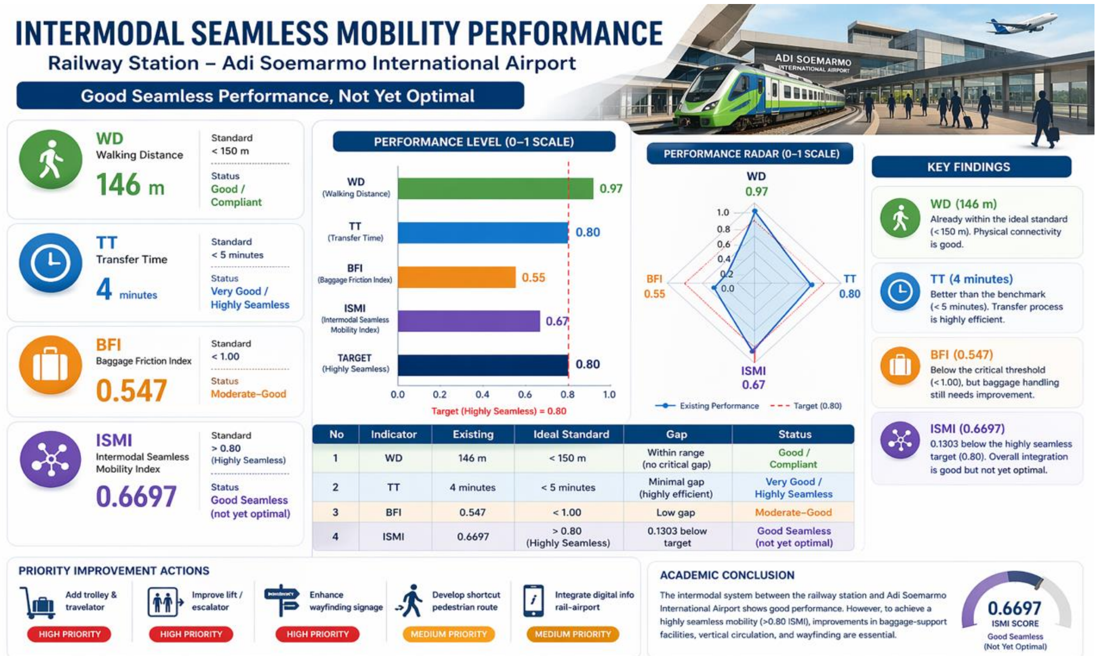

Figure 2. Infrastructure-Based Evaluation of Rail–Airport Seamless Mobility Connectivity at Adi Soemarmo International Airport

Strategies to Improve ISMI toward Highly Seamless Performance

Based on the Gap Analysis results, the passenger transfer system at Adi Soemarmo International Airport is already performing well. However, to elevate the Intermodal Seamless Mobility Index (ISMI) from Good Seamless to Highly Seamless (> 0.80), further optimization is required in three key components: Walking Distance (WD), Transfer Time (TT), and Baggage Friction Index (BFI). To achieve this, the target conditions for a Highly Seamless ISMI are summarized in Table 6 below.

Table 6. Target Conditions for Achieving Highly Seamless ISMI from Existing WD, TT, BFI, and ISMI

No	Indicator	Existing Condition	Ideal Target (Highly Seamless)	Improvement Direction
1	WD	146 m	≤ 120 m	Shorten pedestrian path through layout optimization and direct access design
2	TT	4 minutes	≤ 3 minutes	Reduce micro-delays (orientation, waiting, vertical circulation time)
3	BFI	0,547	≤ 0,35	Improve baggage facilities (trolleys, travelators, barrier-free access)
4	ISMI	0,6697	> 0,80	Achieve highly seamless integration through system-wide optimization

4. DISCUSSION

The results of this study demonstrate that the intermodal passenger transfer system between the railway station and Bandar Udara Adi Soemarmo exhibits a generally high level of performance in terms of Intermodal Seamless Mobility (ISM). The calculated ISMI value of 0.6697 places the system within the **Good Seamless** category, indicating that the integration between rail and air transport modes has been functionally effective, efficient, and relatively comfortable for passengers (Givoni & Banister, 2010; Preston, 2012). From the perspective of individual performance indicators, the Walking Distance (WD) of 146 meters remains within the acceptable range of intermodal transfer design standards (≤150 meters). This suggests that the spatial configuration of the corridor is already efficient in supporting pedestrian movement between modes. However, opportunities remain for optimization through spatial reconfiguration and the reduction of indirect routing (Vuchic, 2005; Hine & Scott, 2000).

The Transfer Time (TT) of 4 minutes reflects a highly efficient transfer process and is already better than the ideal benchmark (<5 minutes). This performance is primarily driven by relatively short distances, clear access pathways, and smooth passenger flow. Nevertheless, minor inefficiencies still exist in vertical circulation and wayfinding transitions, which contribute to residual micro-delays (Wardman, 2004; Ceder, 2007). Meanwhile, the Baggage Friction Index (BFI) of 0.547 indicates moderate baggage handling difficulty. Although the value is still below the critical threshold (1.00), it reveals that passengers continue to experience friction related to vertical movement, corridor transitions, and limited baggage-support facilities. This suggests that the baggage handling subsystem is the most sensitive factor influencing overall mobility comfort (de Neufville & Odoni, 2013; Hine & Scott, 2000).

Overall, the findings confirm that the current multimodal integration is operationally effective but has not yet achieved a fully optimized highly seamless mobility condition (>0.80 ISMI). The system performance is therefore characterized as functionally integrated but partially constrained by micro-level design inefficiencies. Future improvement strategies should prioritize baggage-support infrastructure, intuitive wayfinding systems, and smoother vertical circulation in order to enhance passenger experience and overall intermodal competitiveness (Rodrigue et al., 2020; Christopher, 2016).

Recommendations

To enhance system performance and elevate ISMI from Good Seamless to Highly Seamless, targeted interventions are required across three key dimensions:

a. Walking Distance Optimization (WD)

1) Implement direct access corridors between the railway station and terminal without deviation.
2) Reconfigure terminal entry points to minimize spatial separation from rail access nodes.
3) Develop dedicated shortcut pedestrian corridors exclusively for rail–air passengers.
4) Install travelator systems to reduce perceived walking effort.

Target improvement: WD reduced from 146 m to approximately 120 m.

b. Transfer Time Reduction (TT)

1) Introduce dedicated high-capacity escalators and elevators for transit passengers.
2) Remove physical bottlenecks by widening corridors and access gates.
3) Improve real-time wayfinding systems starting from the platform exit.
4) Implement passenger flow separation strategies to minimize congestion.

Target improvement: TT reduced from 4 minutes to 2.5–3 minutes**.**

c. Baggage Friction Reduction (BFI)

1) Provide baggage trolleys directly at platform level**.**
2) Install wide, baggage-friendly elevators along primary movement routes.
3) Optimize corridor surfaces using smooth, low-resistance travel systems (e.g., travelators)**.**
4) Introduce porter or assistance services for passengers with high baggage loads or special needs.

Target improvement: BFI reduced from 0.547 to ≤0.35. From a system perspective, these interventions collectively aim to strengthen both physical connectivity and functional usability, ensuring that integration is not only infrastructural but also experiential.

5. CONCLUSION

a. This study confirms that the rail–airport multimodal transportation system at Adi Soemarmo International Airport has achieved a Good Seamless (ISMIS = 0.6697) level of intermodal integration. The system demonstrates strong performance in walking distance efficiency and transfer time, while baggage handling remains the most critical area for improvement.
b. Although current conditions already support efficient intermodal mobility, the system has not yet reached the Highly Seamless Mobility threshold (>0.80). Therefore, strategic improvements focusing on spatial optimization, passenger flow efficiency, and baggage handling infrastructure are required.
c. In conclusion, the integration system is functionally successful but not yet fully optimized, and with targeted enhancements, it has strong potential to become a model of high-performance multimodal transport integration in regional airport systems in Indonesia.

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