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Developing a conceptual simulation model to analyze and improve traffic flows of the multimodal terminal "RIX" and decision-making for the formation of a new transport hub

Sofija Kostina[1] A-D,F, Konstantins Savenkovs[1] C-G, Vladimirs Reiskarts[1] A,C,G

[1] Riga Aeronautical Institute, Riga, 9, Mezhkalna str., Riga, LV-1058, Latvia

Original article

Abstract

The article explores the development of a simulation model as a decision support tool to aid the planning and development of a new multimodal transport hub at Riga International Airport (RIX), considering its integration with the Rail Baltica project. The study addresses the growing significance of multimodality in enhancing connectivity, passenger service quality, and infrastructure efficiency at major air transport hubs. The air transport system – comprising both demand-side (passengers, freight) and supply-side (airports, airlines, air traffic control) components - has long been affected by capacity constraints, congestion, and environmental issues. These challenges have persisted and, in some cases, intensified in the post-pandemic recovery period.

The aim of the study is to develop a conceptual simulation model that supports tactical decision-making for traffic flow optimization and infrastructure development at RIX. The research emphasizes complementary role of rail transport in multimodal integration, particularly its potential to extend air connectivity and enable seamless "door-to-door" travel chain. Best practices in multimodality at Helsinki and Singapore airports are reviewed. The current state of infrastructure and intermodal connectivity at RIX is analyzed, especially with reference to its future connection to the planned Rail Baltica line.

A holistic approach to service level analysis is applied, incorporating both terminal and regional access components. Given the complexity of such large-scale projects, modern model-based tools are essential for evaluating alternative scenarios and supporting planning decisions. The proposed conceptual simulation model provides a methodological framework for evaluating multimodal passenger flows and supports strategic decisions on hub development and infrastructure optimization.

Keywords

- multimodality
- hubs
- RIX
- Rail Baltica
- passenger
- traffic flows
- conceptual simulation model
- optimization

Authors contributions

A – Preparation of the research project
B – Assembly of data for the research undertaken
C – Conducting of statistical analysis
D – Interpretation of results
E – Manuscript preparation
F – Literature review
G – Revising the manuscript

Corresponding author

Konstantins Savenkovs
e-mail: k.savenkovs@rai.lv
Riga Aeronautical Institute
Riga, 9, Mezhkalna str.
Riga, LV-1058, Latvia

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Conflict of interest

None declared.

Introduction

In recent decades, air transport system has become a fundamental pillar of global mobility and economic growth. The system comprises two interdependent components: demand—represented by passengers and freight traffic—and supply, including airports, airlines, and air traffic control. Even prior to the COVID-19 pandemic, the sector struggled with increasing demand pressures, including capacity constraints at major airports, congestion, operational delays, and mounting environmental concerns [1]. While the pandemic temporarily alleviated some of these issues, it also reinforced others, highlighting the need for more flexible, sustainable, and integrated infrastructure solutions.

An airport functions as a nodal point in the transport network in a broad sense and includes both airside and landside areas. Consequently, evaluating the transportation service level of a given airport requires a holistic approach—one that considers not only internal terminal operations but also the accessibility and capacity of surrounding infrastructure [1]. In this context, intermodality—the seamless integration of various transport modes—has become a key concept in European transport policy aimed at improving efficiency, sustainability, and user experience.

This paper examines the development of a multimodal transport hub at Riga International Airport (RIX), closely linked to the Rail Baltica project. The study investigates the integration of intermodal infrastructure including direct railway and bus connections to the airport in order to establish a unified and efficient transport network. Interactions between different transport modes can be classified as competitive, complementary, or cooperative. This research considers complementarity as the foundation of effective intermodality, where, for example, rail transport extends the functionality of air travel, enabling door-to-door journey chains and enhancing travel continuity through coordinated schedules and integrated services [4].

Given the complexity of planning, reconstructing, and managing multimodal transport hubs, modern decision-support tools are indispensable. Among various approaches, model-based decision-making is particularly suitable for this type of infrastructure development [2,3]. This method allows stakeholders to explore alternative solutions, conduct scenario analyses, and assess system performance under varying conditions [5, p. 497; 6].

The present research aims to develop a simulation model that supports tactical decision-making in the establishment of a new transport hub at RIX and to demonstrate its potential in addressing management challenges. The model seeks to optimize traffic flows, improve infrastructure utilisation, and support strategic airport planning.

The study object is the landside infrastructure of Riga International Airport and its surroundings as an example of multimodal hub infrastructure. The study subject is the simulation model as a decision-support tool for traffic flow optimization and transport hub development.

The research combines a literature review on multimodal transport systems and simulation modelling approaches, data collection and analysis from the RIX and Rail Baltica projects, and the development of both conceptual and computational model using AnyLogic software. Simulation experiments were conducted to assess system performance under various scenarios, and the results were analysed to draw conclusions and provide recommendations for infrastructure planning and management. This comprehensive approach integrates theoretical research, practical modelling, and quantitative analysis to address contemporary challenges in transport infrastructure and contributes to the development of efficient, resilient, and user-oriented airport hubs.

Implementation of the presented project faces significant financial and regulatory constraints (as of June 2025). The deadlines for the development of the Rail Baltica railway line projects have been repeatedly extended with the last completion date set for December 31, 2024. Latvia has lost access to available but unused Connecting Europe Facility (CEF) funding for design works—provisionally more than 17 million euros. Moreover, national building codes and land expropriation regulations hinder the timely completion of a project of this scale. So far (as of June 2025), CEF-funded design works have been completed only for two Rail Baltica facilities—Riga Central Railway Station and the railway station at Riga International Airport. At the end of 2024, the Ministry of Transport once again appealed to the Cabinet of Ministers with a request to allocate additional funding—3.86 million euros—to cover the costs of designing Rail Baltica. Meanwhile, discussions on Public-Private Partnership (PPP) are ongoing to attract potential investors [7].

Results

This section presents the results of the conceptual simulation model and scenario analysis of passenger and traffic flows at RIX. For this purpose, the conceptual simulation model RIX Terminal was developed and used to analyze various scenarios. This model is represented graphically in Figure 1. The development of the conceptual simulation model included:

Type: Agent-Based and Process-Oriented

Tool: AnyLogic software
Agents: passengers, cars, buses, trains, personnel
Modes: Road (cars, taxis), Rail (Rail Baltica), Air
Infrastructure: pedestrian bridges, drop-off zones, parking areas, taxi lanes
Inputs: timetables, arrival rates, traffic and pedestrian data

Functions:

- Simulate traffic and passenger flows;
- Test scenarios (e.g., increased demand);
- Output: congestion, queue lengths, utilization rates;
- Support terminal planning and Rail Baltica integration.

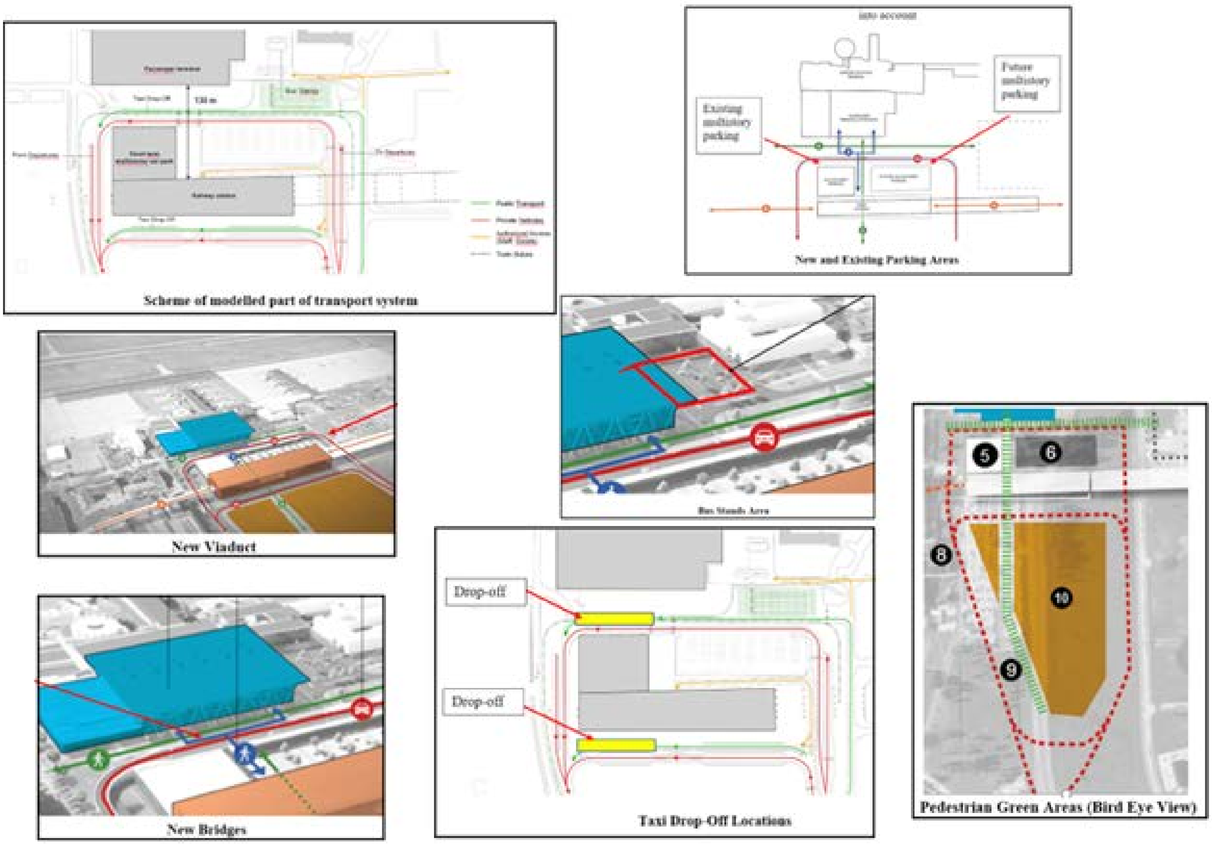

Figure 1. Support terminal planning and Rail Baltica integration

Source: Authors' elaborations based on AnyLogic.

Model overview: The modeled transport system incorporates several key infrastructure components, including new access roads for both public and private transport, a viaduct leading to the terminal's third level, new pedestrian bridges, and designated taxi drop-off locations. The simulation captures interactions between passengers and vehicles within this network, evaluating how well each transport mode performs under normal operational conditions.

Develop a simulation model in Anylogic

Static infrastructure representation

The model assumes that infrastructure elements (e.g., roads, pedestrian bridges, taxi drop-off points) remain constant throughout the simulation and reflect the planned design.
Main assumptions:

1. Fixed transport capacities.
2. Morning peak hour as representative period.
3. Agent-based behavior is predictive.
4. Real-time schedules and historical data are reliable.

Simulation inputs: The simulation operates under a standard scenario that reflects real-time schedules for buses, trains, cars, and taxis, alongside data on passenger flow and transport mode capacities. The model input structure is presented in Tables 1–3. The capacity for each transport mode is defined, with 105 passengers per bus, 560 per train, and 4 per car or taxi. The model enables the exploration of different scenarios by varying traffic and passenger flow intensities to identify potential bottlenecks and system capacity constraints. Figures 2–6 show the process flowcharts of the model.

Table 1. Input of simulation model for the standard scenario

Time	Bus schedule	Train schedule	Car schedule	Taxi schedule
11:00 a.m.	1	Each 30 minutes	59	52
11:16 a.m.	1		63	51
11:31 a.m.	0		55	46
11:46 a.m.	0		65	55
12:01 p.m.	2		74	50
12:16 p.m.	0		68	63
12:31 p.m.	1		61	42
12:46 p.m.			59	39

Table 2. Passengers flow data in 2019 an the foreseen data for 2036

Passengers data	UM	2019	2036 (optimistic scenario)
Million annual passenger	[pax/y]	7,8	12.08 (+54%)
Direct Departing PHP	[pax/h]	1,134	2,000 (+77%)
Direct Arriving PHP	[pax/h]	1,534	2,400 (+56%)
Direct arriving PHP, non Schengen	[pax/h]	669	983
Transit arriving PHP, non Schengen	[pax/h]		903

Table 3. Utilization of transport

Type	Capacity @ 100%	Number of Passenger	Calculated utilization (%)
Bus	105	50	48
Train	560	250	45
Car	4	2	50
Taxi	4	3	75

Source (Tables 1–3): Authors' own elaboration.

Processes to be conveyed in the model

Train Process: drop-off and pick up of passengers (at rail station), travel along a start and an end point.

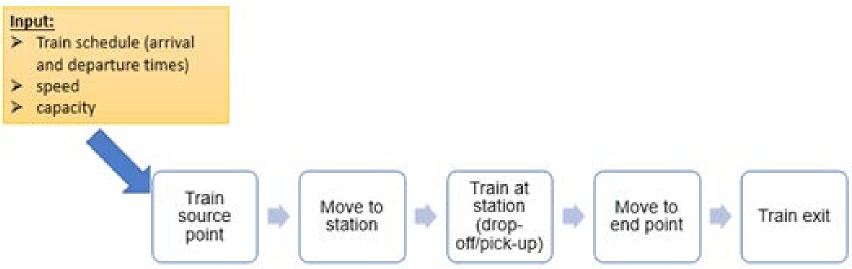

Figure 2. Train process flowchart

Source: Authors' own elaboration.

Bus process: drop-off and pick up of passengers (at bus stands), travel along public transport roads.

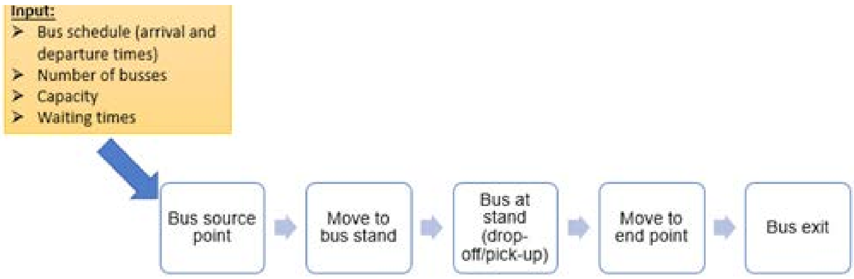

Figure 3. Bus process flowchart

Source: Authors' own elaboration.

Taxi process: drop-off and pick up of passengers (at Taxi drop-off locations), travel along public transport roads.

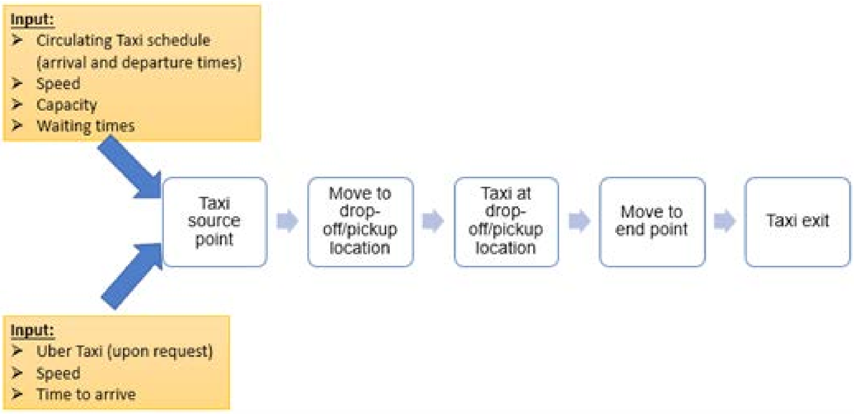

Figure 4. Taxi process flowchart

Source: Authors' own elaboration.

Private cars process: drop-off and pick up of passengers (at drop-off locations), travel along public transport roads, move from road to parking area to park if needed.

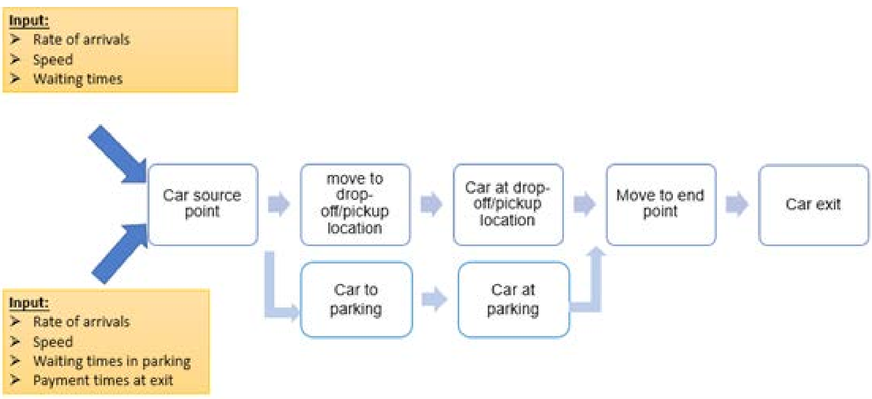

Figure 5. Private cars process flowchart

Source: Authors' own elaboration.

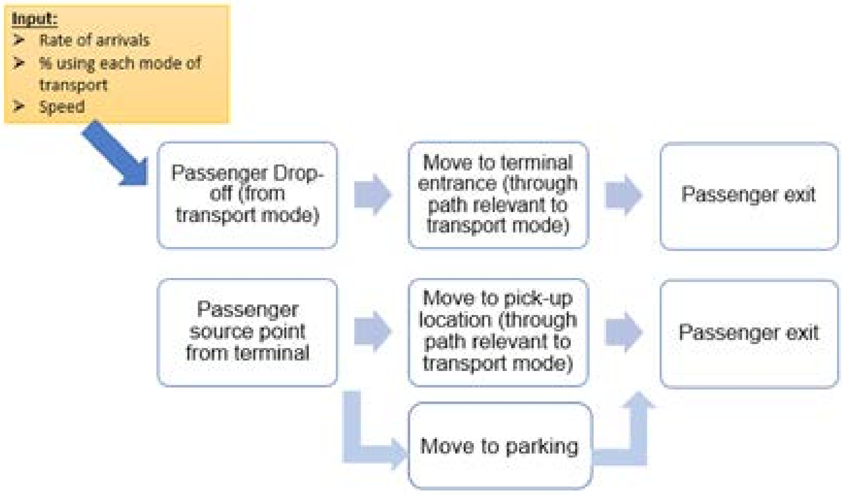

Figure 6. Passengers process flowchart

Source: Authors' own elaboration.

Passengers process: move from drop-off locations (relative to the mode of transport) towards terminal entrance either on the first level or on the third level, move from terminal towards pick-up locations or towards parking, travel along green corridors.

Modeling principles: The simulation applies agent-based modeling techniques, where each transportation mode (bus, taxi, car, train) and each passenger is represented as an independent agents. Agents interact within the system, modeling passenger movements, vehicle arrivals and departures, and the overall transportation process. The use of AnyLogic's libraries for process modeling, pedestrian movement, railway transport, and road traffic ensures that the model accurately reflects real-world dynamics and allows flexible adjustments in operational parameters.

Figure 7. Model process flowchart and statistics for standard scenario

Source: Authors' elaboration based on AnyLogic.

Scenario analysis

The simulation model includes three distinct scenarios to evaluate different aspects of transportation flow:

1. Standard Scenario: This serves as a baseline to assess the current efficiency of the system, highlighting existing waiting times, congestion levels, and utilization rates of various transport modes. Model statistics for the standard scenario is illustrated in Figure 7.
2. Increased Arrival Flow Scenario (by 50%): This scenario investigates the effects of a 50% increase in arriving passengers, examining how this heightened demand influences waiting times, congestion, and the overall efficiency of transportation modes.
3. Increased Departure Flow Scenario (by 50%): Similar to the previous scenario, this one evaluates the impact of a 50% increase in departing passengers, focusing on potential challenges related to congestion and service times during peak departure hours.

Detailed process flowchart for scenario analysis in the simulation model is presented in Figure 8.

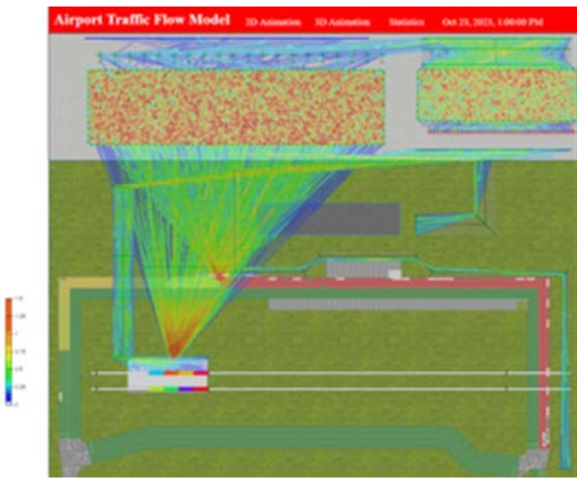

Figure 8. Model process flowchart

Source: Authors' elaboration based on AnyLogic.

Findings

The simulation model provides several key insights into the transportation system:

Bus utilization: The average bus utilization is between 94% and 95%, indicating a high demand for buses, though passenger queues suggest that increasing bus frequency or optimizing bus stand design could alleviate congestion.

Train utilization: Train utilization is lower, ranging from 61% to 67%. The model suggests that improvements in train scheduling and better alignment with passenger flow could help increase the efficiency of this transport mode.

Car and taxi utilization: Both car and taxi services show high utilization rates, with taxi services particularly well utilized (99% in many cases). However, there are instances of under-utilization, particularly in some taxi scenarios, indicating a need for resource reallocation or optimization.

Pedestrian flow: Pedestrian congestion is noted at multiple points within the terminal, particularly during high-demand periods. The model suggests that improvements in pedestrian flow management, such as redesigning walkways or improving crowd control measures, could enhance passenger experience.

Security time: Security check times were found to be efficient, with minimal variation, supporting smoother operations at the terminal.

Scenario results are summarized in Table 2 .

Each scenario is evaluated across five key performance indicators—utilization, queue lengths, security check time, congestion and train usage.

Recommendations

Based on the findings of the simulation, the following recommendations are proposed:

Bus system: Increasing bus frequency or capacity would help reduce queue lengths, especially during peak hours, ensuring a more efficient service.

Train scheduling: Optimizing train arrival intervals could improve the utilization of the train service, especially during peak periods when the current scheduling leads to underutilization.

Taxi services: A more dynamic allocation of taxi resources may help address the fluctuating demand observed, ensuring that taxis are more effectively dispatched to meet passenger needs.

Infrastructure adjustments: Improving the design of bus stands and parking spaces could better align infrastructure with demand, reducing waiting times and improving passenger satisfaction.

Conclusions

The simulation model developed for Riga International Airport (RIX) has proven to be an effective tactical decision-support tool for analyzing the multimodal transport system in the context of future infrastructure

Table 2. Scenario findings comparison

Aspect	Standard Scenario (Baseline)	Increased Arrival Flow (+50%)	Increased Departure Flow (+50%)
Utilization	Bus: 94%, Taxi: 99%, Car: 41%, Train: 67%	Bus/Car/Taxi: >94%, Train: 61%	Bus: 96%, Car/Taxi: 100%, Train: 53%
Queue Lengths	Bus: 435, Car: 137, Taxi: 135	Significantly increased queues in all transport modes	Bus: 429, Car: 203, Taxi: 65
Security Check Time	Avg: 0.33 hrs, Max: 2.74 hrs	Avg: 0.74 hrs	Not specified, but assumed to be higher
Congestion	Moderate congestion in key areas	High congestion in pedestrian and road networks	Highest congestion observed in all networks
Train Usage	Moderate utilization (67%)	Slight drop (61%), relatively stable	Under-utilized (53%) despite high outbound demand

Source: Authors' elaboration based on AnyLogic.

integration, particularly with the planned Rail Baltica connection. The model has revealed current bottlenecks in passenger flows, especially during peak hours, and provided actionable recommendations for optimizing operational parameters such as bus schedules, taxi allocation, and rail connectivity.

Critically, the simulation results underscore that the existing infrastructure, even with targeted improvements, is insufficient to handle the projected growth in passenger volumes. Therefore, the construction of a new multimodal transport hub is not only justified but increasingly urgent.

Nevertheless, the implementation of Rail Baltica, a central element of this future hub currently faces significant risks. The project timeline has already been extended multiple times, and Latvia has forfeited over €17 million in unused CEF (Connecting Europe Facility) funding due to delays in project design [8]. Moreover, at the end of 2024, the Ministry of Transport again requested an additional funding (€3.86 million) to cover further design expenses—indicating systemic budget shortfalls and inefficient planning processes.

These financial challenges are compounded by rising inflation, which continues to drive up construction and material costs, and by regional geopolitical instability, which increases investor caution and limits the potential for public-private partnership (PPP) engagement. Taken together, these factors put the timely and complete execution of the Rail Baltica project under serious threat.

In this context, the simulation model serves a dual purpose: it not only provides a basis for optimizing current operations but also offers a data-driven framework to reassess priorities, adapt phasing strategies, and prepare alternative scenarios should funding or implementation timelines continue to shift.

In conclusion, while the simulation reinforces the strategic importance of developing a new transport hub at RIX, the uncertain financial and geopolitical climate demands continuous monitoring, flexible planning, and strengthened coordination between stakeholders to ensure that the vision of integrated multimodality in the Baltic region becomes a reality. Future research should incorporate financial modeling and risk assessment components to support resilient infrastructure planning under uncertainty.

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