FREIGHT FLOW SIMULATION AND OPTIMIZATION ON THE UZBEKISTAN–KYRGYZSTAN–CHINA RAILWAY USING AGENT-BASED MODELING

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Introduction

In the era of globalized trade and interconnected supply chains, efficient freight transportation systems are essential for economic growth. Central Asia's geographic position between Europe and East Asia offers unique opportunities to develop strategic land-based corridors. The proposed Uzbekistan–Kyrgyzstan–China (UKC) railway is expected to become a vital link in the Belt and Road Initiative (BRI), facilitating cargo transport between China and Central Asia, and further extending to Europe and the Middle East.Despite its potential, the UKC railway's operational efficiency remains unexplored in terms of route performance, throughput, and customs-related bottlenecks. This paper aims to evaluate and simulate freight flow along the proposed UKC corridor using agent-based modeling (ABM), identifying key constraints and optimization strategies. By leveraging modern simulation tools, we assess how logistics performance can be enhanced through digitalization, infrastructure development, and institutional coordination.

Methods

This research utilizes agent-based modeling (ABM) as a method to simulate the dynamic behavior of freight transportation systems along the UKC corridor. The AnyLogic simulation platform was selected for its ability to model complex, multi-agent logistics systems, including variable cargo volumes, infrastructure constraints, and customs clearance processes.

Model components include:- **Agents:** Containers, freight trains, terminals, border checkpoints, customs officials.- **Environment:** A geospatial representation of the UKC railway line including node distances, border crossings, and elevation data.

- **Processes:** Loading/unloading, customs clearance, intermodal transfers.

- **Performance indicators:** Average delivery time, cargo throughput per day, terminal utilization rate.

Input data was collected from national statistics agencies and international reports (ADB, UNESCAP), while delay probabilities were estimated based on expert assessments. Three scenarios were modeled: baseline (current infrastructure), optimized infrastructure, and digital customs integration.

Results

Simulation results show that under baseline conditions, the average delivery time from Kashgar (China) to Tashkent (Uzbekistan) is 9.8 days. In the optimized infrastructure scenario, which includes double-track segments and expanded terminals, the delivery time decreased to 7.2 days.

Further improvements with digital customs systems reduced delays at border checkpoints by 35%.

The throughput capacity of the corridor improved from 18 to 29 trains per day in the optimized scenario, and container loss rates dropped by 15%. Table 1 summarizes the key performance metrics across the three scenarios:

Table 1. Performance Comparison Across UKC Railway Simulation Scenarios

Scenario	Avg. Delivery Time	Trains/Day	Delay Time	Terminal Utilization
Baseline	9.8 days	18	22 hours	76%
Optimized Infrastructure	7.2 days	24	16 hours	83%
Digital Integration	6.5 days	29	10 hours	91%

Discussion

The simulation findings suggest that targeted infrastructure upgrades and technological integration can substantially improve the operational efficiency of the UKC railway. Border delays, identified as the most critical bottleneck, can be mitigated through unified customs procedures and shared digital platforms. The gains from optimizing terminal layout and increasing capacity at major intermodal hubs also significantly reduced congestion-related delays.The agent-based approach provides a flexible and scalable tool to test different policy and investment scenarios. For example, the implementation of electronic documentation and pre-arrival processing at border points can reduce clearance times by up to 50%.

These findings align with global best practices observed on other corridors such as the China–Kazakhstan–Russia route. However, the UKC route's advantage lies in its shorter geography and integration with southern Eurasian markets, offering a strong complement to existing networks.

Conclusion

Agent-based modeling of the UKC railway demonstrates that freight flow optimization can unlock substantial gains in efficiency and capacity. Policy reforms targeting customs automation and infrastructure modernization are key enablers of success. Future work should focus on integrating real-time data feeds from railway operations to enhance model accuracy. Additionally, stakeholder coordination across borders remains essential for sustainable corridor development.

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