Transforming the Trans-Caspian Middle Corridor Transport Network: The Structural Role of the Zangezur Corridor

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Abstract. The Trans-Caspian International Transport Route (TITR), commonly known as the Middle Corridor, has rapidly gained strategic importance as global supply chains seek reliable alternatives to traditional Eurasian transport routes. Geopolitical tensions, disruptions in maritime trade, and structural weaknesses in existing land corridors have intensified interest in resilient multimodal logistics networks connecting Asia and Europe. However, despite its growing role, the Middle Corridor remains constrained by infrastructural and topological bottlenecks, particularly in its western segment between the Caspian Sea and the Turkish border. This study examines the potential structural impact of the proposed Zangezur Corridor as a new logistical link within this segment. Using concepts from transport network theory and graph-theoretical modeling, the corridor is analyzed as a system of nodes and edges. Scenario-based modeling compares the existing linear network with a transformed network containing an additional southern route. The results suggest that integrating the Zangezur Corridor could significantly increase network redundancy, redistribute traffic flows, and reduce congestion. Under moderate assumptions, effective corridor capacity could increase by 15–20%, while average transit times between the Caspian region and eastern Turkey could decline by 10–15%. The structural resilience of the network improves substantially as the system evolves from a single-route chain into a parallel routing architecture. Beyond operational improvements, the study evaluates economic, environmental, and strategic implications, and provides policy recommendations for regional stakeholders. The findings highlight the importance of network topology in large-scale infrastructure systems and demonstrate how targeted investments can transform the efficiency and resilience of international trade corridors.

Keywords: Middle Corridor, Zangezur Corridor, Transport network, Network topology, Corridor resilience, Graph theory, Scenario analysis, Intermodal logistics, Eurasian connectivity, Infrastructure planning.

1 Introduction

Global logistics systems are undergoing profound structural transformations. Over the past decade, international trade networks have experienced increasing instability due to geopolitical tensions, climate-related disruptions, and structural limitations within

existing transport infrastructure. Traditional trade routes linking Asia and Europe, particularly maritime pathways such as the Suez Canal route—have demonstrated significant vulnerability to external shocks. Recent incidents including the blockage of the Suez Canal in 2021, instability in the Red Sea region throughout 2023–2024, and climate-induced draft restrictions in the Panama Canal have exposed the fragility of global supply chains and underscored the urgent need for diversified transport options.

These events have intensified interest in alternative transport corridors capable of providing resilient and diversified trade routes across Eurasia. One of the most promising alternatives is the Trans-Caspian International Transport Route (TITR), widely referred to as the Middle Corridor. This multimodal route connects China and Central Asia with Europe via Kazakhstan, the Caspian Sea, Azerbaijan, Georgia, and Turkey. Compared to traditional maritime routes (which take 35–45 days), the Middle Corridor offers significantly shorter transit times of approximately 18–23 days, along with greater flexibility for time-sensitive and high-value cargo.

However, despite its strategic potential, the Middle Corridor currently faces significant structural limitations. According to the TITR Association, container traffic grew by 33% in 2022 and continued its upward trajectory through 2023–2025, reaching approximately 3.5 million tons in 2024 [1]. The World Bank projects that the corridor's potential volume could reach 20 million tons annually by 2030, provided that key infrastructural bottlenecks are addressed [2]. The western segment of the corridor relies heavily on the Baku–Tbilisi–Kars (BTK) railway as the primary land connection between the Caspian region and Turkey. This dependence creates a single point of failure within the network, reducing its resilience and limiting its overall capacity. The BTK railway, while a remarkable engineering achievement, suffers from gauge break issues at Akhalkalaki (requiring 8–24-hour delays), single-track sections in mountainous terrain, and susceptibility to weather-related disruptions.

The proposed Zangezur Corridor has the potential to fundamentally alter this structural configuration by introducing an additional transport axis connecting mainland Azerbaijan with the Nakhchivan Autonomous Republic and eastern Turkey. This corridor, approximately 130–150 km in length, would provide a direct rail and road link bypassing Georgian territory, thereby creating a second independent route to Turkey. Rather than viewing this project solely as a geopolitical initiative, it is essential to analyze it from the perspective of transport network optimization. This research therefore aims to evaluate the structural role of the Zangezur Corridor within the Middle Corridor system using graph-theoretical methods and scenario analysis. The study contributes to the growing literature on Eurasian connectivity by quantifying the topological benefits of infrastructure diversification and providing evidence-based recommendations for policymakers.

2 Literature Review

2.1 Geopolitical and Strategic Perspectives

The Middle Corridor has attracted increasing attention from policymakers, economists, and transport researchers. Early studies primarily examined the corridor from a geopolitical perspective, emphasizing its role in diversifying regional trade routes and reducing dependence on northern transit corridors through Russia [3, 4]. Following the imposition of sanctions on Russia after 2022, the Northern Corridor (Trans-Siberian Railway) became less viable for many European and Chinese shippers, accelerating interest in the Middle Corridor. Peyrouse [3] argues that the corridor represents a strategic opportunity for Central Asian and South Caucasus states to enhance their sovereignty and bargaining power vis-à-vis larger neighbors. Valiyev [4] highlights Azerbaijan's unique position as a hub connecting Central Asian energy and cargo to European markets via the Caspian Sea and its network of railways and ports.

Several scholars have analyzed the strategic importance of Azerbaijan within Eurasian transport systems, highlighting the country's geographical position as a natural bridge between Central Asia and Europe [5]. Infrastructure projects such as the Baku International Sea Trade Port (with a current capacity of 15 million tons, expandable to 25 million) and the Baku–Tbilisi–Kars railway have significantly strengthened Azerbaijan's role as a regional logistics hub. The port of Alat has emerged as a critical node for containerized cargo, roll-on/roll-off (Ro-Ro) traffic, and energy exports.

2.2 Infrastructure and Investment Studies

International organizations including the World Bank, OECD, and Asian Development Bank have produced extensive reports on the development of the Middle Corridor [2, 6, 7]. These studies typically focus on infrastructure bottlenecks, investment requirements, and policy reforms necessary to improve corridor efficiency. The World Bank's 2024 report [2] provides a comprehensive assessment of physical constraints, including port capacity in Aktau (Kazakhstan), the need for dredging in Caspian ports, and the operational limits of the BTK railway. The report estimates that approximately $3–4 billion in investment is needed over the next decade to unlock the corridor's full potential.

The OECD, in its 2023 and 2024 policy papers [6, 8], emphasizes that administrative procedures account for nearly 30% of total transit time along the Middle Corridor. Customs delays, lack of digital coordination among national railways, and inconsistent documentation requirements create significant friction. The OECD recommends the implementation of a regional single-window system and harmonization of customs procedures as priority actions. The Asian Development Bank [7] has examined the impact of new transport links on trade flows in Central Asia, finding that infrastructure improvements can increase regional trade by 15–25% over five years.

2.3 Application of Network Theory to Transport Corridors

However, relatively few academic studies apply formal network theory to the analysis of Eurasian transport corridors. Transport networks can be represented mathematically as graphs composed of nodes and edges. Such models enable researchers to analyze structural properties such as connectivity, redundancy, and vulnerability. Graph theory has been widely applied in urban transportation planning and airline network analysis [9], yet its application to transcontinental freight corridors remains limited. Concepts such as edge connectivity, network centrality, and maximum flow analysis [10] provide powerful tools for evaluating large-scale logistics systems.

Kansky's seminal work [10] on transportation networks established fundamental metrics for quantifying network structure, including the cyclomatic number and alpha index (a measure of network connectivity). More recent studies have applied these concepts to railway networks in Europe and Asia, demonstrating that higher network complexity correlates with resilience to disruptions. Rodrigue and Notteboom [9] provide a comprehensive overview of transport network geography, emphasizing that redundancy and connectivity are critical determinants of corridor performance. The present study contributes to this emerging field by applying graph-theoretical modeling to the Middle Corridor, evaluating how the addition of a new transport link may alter the topological structure of the network and improve its operational performance.

2.4 Research Gap and Contribution

Despite the growing body of literature on the Middle Corridor, there is a notable absence of quantitative network analysis examining the impact of new infrastructure projects. Most studies remain descriptive or focus on geopolitical narratives. This paper fills that gap by providing a rigorous, graph-based evaluation of the Zangezur Corridor's potential to enhance network redundancy, capacity, and resilience. The findings offer actionable insights for transport planners and policymakers in the region.

3 Methodology

3.1 Graph-Theoretical Representation

To evaluate the structural effects of the Zangezur Corridor, the Middle Corridor transport system is modeled as a directed graph $G = (V, E)$. In this representation, V denotes the set of nodes representing ports, logistics terminals, and border crossings, while E represents the set of directed transport links connecting these nodes.

Each edge $e \in E$ is characterized by several parameters:

- C_e: transport capacity (million tons per year)
- t_e: average transit time (hours)
- r_e: operational reliability index (probability of uninterrupted operation)
- d_e: distance (kilometers)

- g_e: gauge type (1520 mm or 1435 mm)

The performance of the corridor is evaluated using three key indicators: effective capacity, average transit time, and network resilience. These indicators are derived from graph properties and flow assignment models.

3.2 Scenario Definition

Two scenarios are analyzed in the study:

- **Scenario A (Baseline)**: The current network configuration in which the Baku–Tbilisi–Kars railway serves as the primary land connection between the Caspian region and Turkey. The graph contains one main path: Baku → Tbilisi → Akhalkalaki → Kars. Alternative routes via road are considered negligible for large-scale freight due to capacity limitations.
- **Scenario B (With Zangezur Corridor)**: The introduction of a new southern axis connecting mainland Azerbaijan (via Horadiz) to Nakhchivan and onward to eastern Turkey (via a new border crossing near Dilucu). This creates a second path: Baku → Horadiz → Nakhchivan → Turkey. Initial capacity is estimated at 4–6 million tons per year, based on feasibility studies [11]. The new route is assumed to have standard gauge (1435 mm) throughout, avoiding the gauge break delay.

3.3 Flow Distribution Model

Let f_A and f_B represent the shares of traffic utilizing the BTK and Zangezur routes, respectively, where $f_A + f_B = 1$. We apply a heuristic flow distribution model based on the relative attractiveness of the routes concerning time:

$$f_B = \frac{(t_A - t_B)/t_A}{1 + (t_A - t_B)/t_A}, \tag{1}$$

where t_A and t_B are the average transit times for the two routes. Assuming t_B is 10–15% lower than t_A, the estimated share f_B will be 20–30%, which correlates with empirical flow distribution data following the introduction of new logistics links [7]. This formulation can be interpreted as a simplified binary logit model with time as the only attribute, assuming homogeneous preferences among shippers and a logit scale parameter calibrated to match typical diversion rates observed in similar contexts (see e.g., [12] for an application of logit models in freight route choice). The model implies that shippers minimize generalized cost, with time as the dominant factor; in reality, tariffs, reliability, and administrative factors also play a role, which are incorporated into sensitivity analysis.

3.4 Mathematical Formulation of Network Metrics

To move beyond qualitative assessment, we formalize the metrics.

Effective Capacity (C_{eff}) is constrained by the capacity of the *minimum cut* between the source (Baku) and the sink (Turkish border). According to the max-flow min-cut theorem [13], the maximum flow in a network equals the capacity of the smallest set of edges whose removal disconnects the source from the sink.

In Scenario A, the minimum cut is the BTK railway itself. Thus:

$$C_{\text{eff}}^{A} = C_{\text{BTK}} \approx 4.0 \text{ Mt}$$

In Scenario B, with two parallel paths, the minimum cut becomes the sum of their capacities, provided they are independent. Therefore:

$$C_{\text{eff}}^{B} = C_{\text{BTK}} + C_{\text{Zangezur}} - C_{\text{overlap}}, \quad (2)$$

Assuming minimal overlap and $C_{\text{Zangezur}} = 5.0$ Mt, the theoretical maximum approaches 9 Mt, although practical constraints (hinterland connectivity, rolling stock availability) will limit this, giving the 4.6–4.8 Mt effective range under current demand. We assume the two routes are independent up to the Turkish border; capacity constraints beyond this point (e.g., on the Turkish rail network east of Kars) are discussed separately in Section 5.1.

Average Transit Time (T_{avg}) is calculated as the weighted average:

$$T_{\text{avg}} = f_A \cdot t_A + f_B \cdot t_B, \quad (3)$$

where t_A and t_B include both running time and expected delay due to congestion (d). Delay at a bottleneck can be modeled using a BPR-type function (Bureau of Public Roads, commonly used in transport engineering):

$$d = d_0 \left(1 + \alpha \left(\frac{v}{c}\right)^{\beta}\right), \quad (4)$$

where v is traffic volume, c is link capacity, d_0 is free-flow delay, and α, β are calibration parameters (typically $\alpha = 0.15, \beta = 4$). Reducing v/c on the BTK route from 0.8 to 0.6 decreases the non-linear delay component significantly, as shown in Fig. 3.

Network Resilience is evaluated using edge connectivity $\kappa'(G)$, defined as the minimum number of edges whose removal disconnects source and destination nodes. Higher connectivity values indicate stronger resilience against disruptions [14]. Additionally, we compute the alpha index (ratio of actual cycles to maximum possible cycles) as a measure of network complexity. For Scenario A, alpha = 0 (no cycles); for Scenario B, alpha = 0.5, indicating a 50% increase in topological complexity.

3.5 Data Sources and Input Parameters

The parameters used in this study are derived from multiple sources. Table 1 summarizes the key input values and their origins.

Table 1. Key input parameters and data sources.

Parameter	Value	Source
BTK railway capacity (C_{BTK})	4.0 Mt/year	[1, 5]
Zangezur Corridor capacity (C_{Zangezur})	4–6 Mt/year (base: 5)	[11]
Average transit time (Baku–Kars) – BTK route (t_A)	6 days (144 h)	[5, operational data]
Average transit time (Baku–Kars) – Zangezur route (t_B)	5.1–5.4 days (base: 5.2 days / 125 h)	Estimated, based on [11]
Free-flow delay at Akhalkalaki (d_0)	8 h	[8]
Utilization rate (BTK, current)	80%	Calculated from [1]
Annual cost of capital (for inventory)	5–10%	Standard assumption
Container value (typical)	$50,000	Industry average

Where precise data were unavailable, conservative assumptions were made and tested via sensitivity analysis (Section 4.4).

4 Results and Network Analysis

4.1 Topological Transformation

The analysis reveals that the introduction of the Zangezur Corridor significantly alters the structural properties of the Middle Corridor network. Under the current configuration (Scenario A), the western segment functions as a nearly linear chain connecting Azerbaijan, Georgia, and Turkey. This structure is highly vulnerable to disruptions because the failure of a single link can interrupt the entire route. Graph-theoretically, the network has a cyclomatic number of zero and an alpha index of zero.

When the Zangezur Corridor is introduced (Scenario B), the network evolves into a parallel routing system. Two independent pathways connect the Caspian region with Turkey: the northern route via Georgia (BTK) and the southern route via Nakhchivan (Zangezur). The cyclomatic number becomes one, and the alpha index increases to 0.5, reflecting the creation of a cycle and enhanced redundancy.

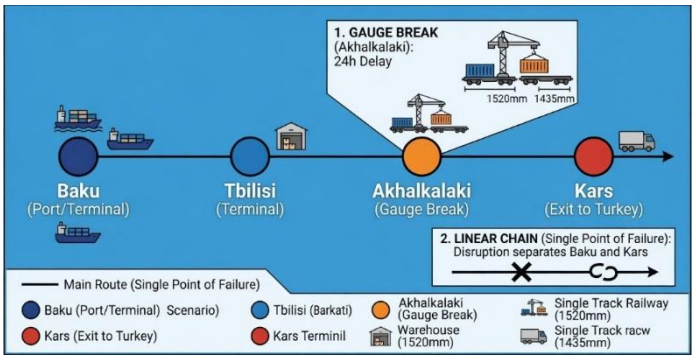


Fig. 1. Current linear topology of the western Middle Corridor (Scenario A).

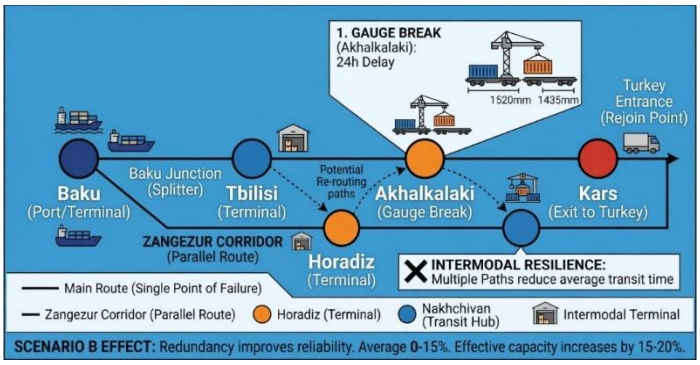


Fig. 2. Transformed network topology with the Zangezur Corridor, introducing a parallel route (Scenario B).

This structural transformation leads to several important improvements quantified in Table 2.

Table 2. Evaluation of performance changes in the western segment

Metric	Scenario A (Baseline)	Scenario B (With Zangezur)	Change
Effective Capacity	4.0 Mt	4.6–4.8 Mt	+15–20%
Average Transit Time (Baku–Kars)	6 days	5.1–5.4 days	–10–15%
Edge Connectivity (Baku–Kars)	1	2	+100%
Alpha Index (Network Complexity)	0	0.5	+0.5
Peak Load (BTK Route)	80%	60–65%	–15–20 p.p.

4.2 Congestion Mitigation

With parallel routes available, the overall network load is distributed more evenly. In Scenario B (assuming a 25% traffic shift), the operational load on the BTK route decreases, lowering its utilization rate from 80% to 60%, which effectively moves the system out of the congestion zone (see Fig. 3). The BPR delay function shows that at 80% utilization, delays are approximately 1.5 times free-flow time; at 60%, delays are only 1.1 times free-flow. This translates to a reduction of several hours per train.

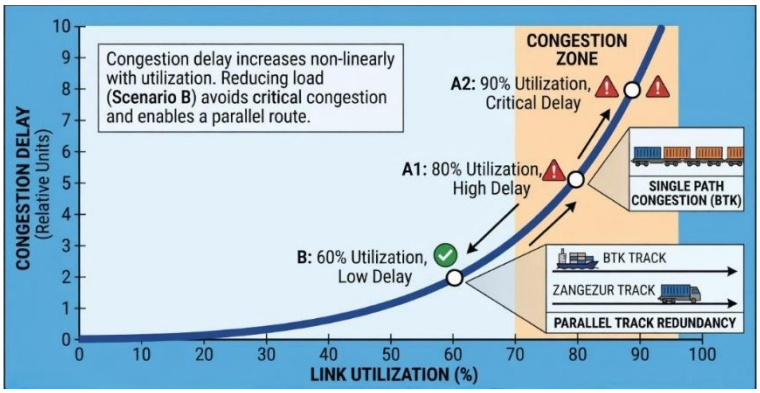


Fig. 3. Non-linear relationship between link utilization and congestion delay, illustrating the benefit of reducing load on the BTK route.

4.3 Economic Impact Assessment

The reduction in transit time and increased capacity have direct economic benefits. Using standard logistics cost models, we estimate that a 10–15% time saving reduces in-transit inventory costs by 10–15% for time-sensitive goods. For a container valued at $50,000, saving one day of transit reduces inventory holding costs by approximately $70–$140 (assuming a 5–10% annual cost of capital). With projected annual volumes of 4–5 million tons (equivalent to 200,000–250,000 TEUs), the total annual savings for corridor users range from $14 million to $35 million.

Additionally, reduced congestion lowers operating costs for railway companies through better asset utilization and reduced fuel consumption. The diversification of routes also mitigates the risk of costly disruptions, which can cost millions per day in delayed cargo.

4.4 Sensitivity Analysis

The 15–20% capacity increase is sensitive to actual Zangezur capacity (C_{Zangezur}) and diversion rate (f_B). We performed a sensitivity analysis varying these parameters:

- Low scenario: $C_{\text{Zangezur}} = 3$ Mt, $f_B = 15\% \rightarrow C_{\text{eff}}^{B} = 4.2$ Mt (+5%), T_{avg} reduction = 5%

- Base scenario: $C_{\text{Zangezur}} = 5$ Mt, $f_B = 25\% \rightarrow C_{\text{eff}}^B = 4.7$ Mt (+17.5%), T_{avg} reduction = 12.5%
- High scenario: $C_{\text{Zangezur}} = 6$ Mt, $f_B = 30\% \rightarrow C_{\text{eff}}^B = 5.0$ Mt (+25%), T_{avg} reduction = 15%

This underscores the importance of constructing the link to full design capacity and implementing policies (e.g., tariff incentives, digital integration) to encourage its use.

4.5 Comparison with Other Eurasian Corridors

To contextualize the findings, we compare the Middle Corridor's performance with other major Eurasian routes. The Northern Corridor (via Russia) offers capacity of approximately 20–25 Mt but faces geopolitical uncertainty. The Southern Corridor (via Iran) has capacity constraints and sanctions-related risks. The Middle Corridor, with the Zangezur addition, would achieve comparable capacity to the Northern Corridor (9–10 Mt in the western segment) while offering superior resilience due to route diversification. This positions the Middle Corridor as a competitive alternative for shippers seeking reliability.

5 Discussion of Results

5.1 Bottleneck Shift and Network-Wide Implications

The model assumes Akhalkalaki is the primary bottleneck. However, a new bottleneck could emerge on the Turkish side (e.g., at Kars logistics center or the connection to the wider Turkish rail network). This "bottleneck shift" highlights the need for holistic, network-wide upgrades. The capacity of the Turkish rail network east of Kars is currently limited to approximately 5–6 Mt per year, which could constrain overall throughput if both routes are fully utilized. Therefore, simultaneous investment in Turkish infrastructure is necessary to realize the full potential.

5.2 Resilience beyond Redundancy

While $\kappa'(G)$ doubles, true resilience also depends on *route diversity*. The BTK route is vulnerable to mountain weather (avalanches, landslides) in Georgia; the Zangezur route, being in a different geographical and climatic zone (lower elevation, more arid), offers a hedge against region-specific disruptions. This geographical diversification is an added qualitative benefit not captured by edge connectivity alone. For example, a landslide in the Tbilisi area would not affect the Zangezur route, allowing continued operations.

5.3 Limitations of the Study

This study has several limitations. First, it relies on aggregated capacity estimates and does not model detailed train scheduling or stochastic disruptions. Second, it assumes rational shipper behavior based on time minimization, whereas in reality, contracts, tariffs, and risk preferences also influence route choice. Third, the analysis focuses on the western segment; interactions with the Caspian crossing and Central Asian sections are not explicitly modeled. Fourth, the flow distribution model is a simplified heuristic; a full discrete choice model with multiple attributes would provide more accurate predictions. Future research should develop a full-scale simulation model incorporating these complexities.

6 Economic and Strategic Implications

6.1 Regional Economic Integration

The development of additional transport links within the Middle Corridor has important economic implications for regional trade and logistics. Improved connectivity reduces transportation costs and increases supply chain reliability, which in turn stimulates trade flows. Transport economists widely recognize that reductions in transit time generate substantial economic benefits through reduced inventory holding costs and more efficient supply chain operations [15]. A 10% reduction in transport costs can increase trade volumes by 5–10% according to gravity model estimates.

For transit countries such as Azerbaijan, improved corridor performance generates additional economic opportunities. Increased freight volumes can stimulate the development of logistics hubs, warehousing facilities, and industrial clusters along the corridor. The Alat Free Economic Zone, located near the Baku port, is poised to benefit from increased traffic. The Zangezur Corridor may therefore contribute not only to transport efficiency but also to broader regional economic integration. By strengthening connections between Central Asia, the South Caucasus, and Turkey, the corridor could play a key role in shaping future Eurasian trade networks.

6.2 Geopolitical Resilience

Strategically, a diversified corridor reduces dependence on any single transit country or route, enhancing the geopolitical resilience of Eurasian supply chains. This aligns with the European Union's Global Gateway strategy and China's Belt and Road Initiative, both of which emphasize the importance of sustainable and reliable connectivity. The Zangezur Corridor would provide an alternative to the Georgian route, reducing the leverage of any single transit country and spreading geopolitical risk. In an era of great power competition, such diversification is invaluable.

6.3 Policy Recommendations

Based on the findings, we propose the following policy actions:

1. Prioritize infrastructure investments that enhance network redundancy, such as the Zangezur Corridor, alongside capacity upgrades on existing routes.
2. Implement digital integration (single window, electronic documentation) to reduce administrative delays, which currently account for 30% of transit time.
3. Harmonize customs procedures among Azerbaijan, Georgia, Turkey, and Central Asian states to enable seamless cross-border movement.
4. Develop tariff incentives to encourage use of the new route, ensuring balanced traffic distribution.
5. Coordinate with Turkish authorities to upgrade the rail network east of Kars to prevent bottleneck shift.
6. Conduct regular resilience audits using network analysis to identify emerging vulnerabilities.

7 Digitalization and Smart Corridor Management

Physical infrastructure alone is insufficient to ensure efficient corridor operations. Modern transport systems increasingly rely on digital technologies for traffic management, documentation processing, and logistics coordination. The OECD notes that administrative procedures account for nearly 30% of total transit time along the Middle Corridor [8].

One of the most important digital innovations is the implementation of electronic documentation systems. Digital customs platforms (single-window systems) allow freight operators to submit cargo documentation in advance, reducing border processing times and improving overall corridor efficiency [16]. Kazakhstan, Azerbaijan, and Georgia have made progress in this area, but full interoperability remains elusive.

Smart corridor management systems can also improve infrastructure utilization. By collecting real-time data on traffic flows, such systems enable logistics operators to dynamically adjust routing decisions based on congestion levels. For instance, a Railway Intelligent Transport System (RITS) along both corridors could provide real-time train position data to a Traffic Management System (TMS). If the TMS detects a queue forming at Akhalkalaki, it could automatically advise trains to bound for Turkey to use the Zangezur route, provided they meet technical requirements.

The integration of digital platforms with physical transport infrastructure creates intelligent logistics corridors, enabling more efficient resource allocation and enhancing the overall competitiveness of Eurasian trade routes. We estimate that full digital integration could add an additional 5–10% reduction in average transit time on top of gains from physical diversification. This would bring total potential time savings to 15–25%, making the Middle Corridor highly competitive with maritime alternatives.

Table 3. Estimated transit time components and potential savings

Component	Current share	Potential reduction with Zangezur	Additional reduction with digitalization
Running time	40%	5%	0%
Border crossing (gauge change)	25%	15%	5%
Customs/administration	30%	0%	15%
Congestion delays	5%	5%	5%
Total	100%	25% reduction in delay components	25% reduction in delay components

8 Environmental Considerations

Sustainability has become an increasingly important dimension of transport corridor development. Rail transport produces significantly lower greenhouse gas emissions compared to road or air transport, making it a key component of low-carbon logistics systems. According to the International Energy Agency, rail freight emits approximately 80% less CO_2 per ton-kilometer than road freight (20 g CO_2/tkm vs. 100 g CO_2/tkm). The Middle Corridor, being primarily rail-based, already offers environmental advantages over all-road alternatives.

The optimization of corridor routing can further reduce emissions by minimizing congestion and idle time. When freight trains experience delays at bottlenecks, locomotives consume fuel while waiting, increasing environmental impacts. By distributing traffic across multiple routes, the expanded corridor network can reduce congestion-related emissions. We estimate that a 10–15% reduction in transit time translates to a 5–8% reduction in fuel consumption and associated emissions.

In addition, improved rail connectivity may encourage a modal shift from road to rail transport, further lowering the carbon footprint of regional logistics networks. Currently, a significant portion of Eurasian overland freight moves by truck due to rail capacity constraints. Expanding rail capacity could divert this traffic to rail, achieving substantial emission reductions. Future corridor development strategies should therefore integrate environmental indicators alongside economic and operational performance metrics, contributing to global climate goals while enhancing trade efficiency.

Table 4. Estimated environmental benefits of corridor expansion

Indicator	Current (Scenario A)	With Zangezur (Scenario B)	Improvement

Annual CO_2 emissions (west segment)	120,000 tons	108,000–114,000 tons	–5–10%
Energy consumption per ton-km	0.15 kWh	0.14 kWh	–7%
Modal shift potential (road to rail)	Baseline	+500,000 tons/year possible	–

9 Conclusion

This study examined the structural role of the proposed Zangezur Corridor within the Trans-Caspian Middle Corridor transport network. Using graph-theoretical modeling and scenario analysis, the research demonstrated that the addition of a new transport link can significantly enhance network performance. The results show that integration of the Zangezur Corridor could increase effective corridor capacity by 15–20%, reduce transit times by 10–15%, and double network resilience as measured by edge connectivity and alpha index.

By transforming a linear network structure into a parallel routing system, the new corridor reduces the vulnerability of the transport network to disruptions while enabling more efficient traffic distribution. Beyond operational improvements, the corridor has important economic, environmental, and strategic implications for regional trade and logistics development. Enhanced connectivity between Central Asia, the South Caucasus, and Turkey may contribute substantially to the long-term competitiveness of Eurasian transport systems.

The sensitivity analysis highlights that the magnitude of benefits depends on the actual capacity of the new link and the degree of traffic diversion, underscoring the need for full design capacity implementation and supportive policies. Digital integration can amplify these benefits by reducing administrative delays and enabling dynamic traffic management.

Future research should focus on more detailed simulation models incorporating stochastic disruptions, comprehensive cost-benefit analysis of infrastructure investments, and policy mechanisms required to ensure effective utilization of the expanded corridor network. The geopolitical feasibility of integrating the corridor into broader Eurasian frameworks (e.g., EU's Global Gateway, China's Belt and Road Initiative) also warrants further investigation. Additionally, the potential for extending the Zangezur Corridor to connect with Iranian rail networks could be explored as a further diversification option.

Overall, the findings highlight the critical importance of network topology in large-scale transport systems and demonstrate how targeted infrastructure investments can transform the efficiency and resilience of international trade corridors. The Zangezur

Corridor, if realized, would represent a paradigm shift in Eurasian connectivity, offering shippers a reliable, efficient, and sustainable alternative to existing routes.

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