Multi-Criteria Modeling and Optimization of Multi-modal Logistics in East-West Corridor

Mammadova V.T[0009-0002-1358-8483]

Sumgait State University, Sumgait AZ5008, Republic of Azerbaijan
vusala.mammadova@sdu.edu.az

Abstract. The dynamic development of global trade and the increasing volume of international freight have enhanced the strategic importance of transport corridors. In this context, the effective design and optimization of multimodal logistics systems for organizing freight transport between Europe and Asia have become essential. This article models the logistics network along the East–West Transport Corridor using a graph-theoretic framework. A multi-criteria optimization model is developed by considering transportation cost, transit time, and logistics risks. These criteria are integrated into a single objective function using weights that reflect their relative importance, enabling the determination of optimal routes. The model results suggest that an optimal route may connect major regional nodes, including China, Central Asia, the Caspian region, the South Caucasus, and Europe. The findings show that multi-criteria optimization improves decision-making accuracy and supports efficient logistics planning, risk management, and resource allocation. The methodology provides both theoretical and practical contributions to the development of logistics networks and enhances the efficiency of international transport systems worldwide through systematic and data-driven approaches in practice.

Keywords: Multimodal logistics, Logistics network optimization, Multi-criteria optimization, Mathematical modeling, Graph theory, East–West Transport Corridor.

1 Introduction

The growth of global trade has significantly increased the importance of multimodal transport corridors [1]. Three main routes dominate this system: the Northern Corridor, the Maritime Silk Road, and the Middle Corridor, which offers advantages in sustainability and reduced geopolitical risks [2].

2 Literature Review

Recent studies focus on trade flow optimization and digital integration [3]. Key studies highlight that the Middle Corridor accelerates cargo flows while reducing transit risks compared to northern alternatives [4]. Digital innovations, including blockchain and IoT-based tracking, have been reported to reduce operational costs significantly [5].However, most models focus on single-criterion optimization [6]. There is a notable gap in research addressing the simultaneous integration of cost, time, and risk within a unified mathematical framework, particularly concerning the South Caucasus region's strategic transit role [7].This paper addresses these gaps by employing a multi-criteria Pareto optimization model [8].

3 Research Methodology

This study applies theoretical and applied approaches to model and optimize the East–West Transport Corridor. Analytical tools are used to describe network structure and identify optimal routes [9,10].

3.1 Research Objective and Approach

The research methodology consists of the following stages:

- **Network Construction:** Identification of key logistics nodes connecting China, Central Asia, the Caspian region, South Caucasus, and Europe, using UNCTAD, UNESCAP, World Bank data, and Trans-Caspian Transport reports.
- **Mathematical Model Development:** Nodes (terminals, ports, railway stations) and links (rail, road, sea, air) represented via graph theory.
- **Multi-Criteria Optimization:** Weighted objective function for transport cost, time, and logistics risks.
- **Pareto Optimization:** Determination of compromise solutions.
- **Algorithmic Solution:** Dijkstra's algorithm and weighted graph methods to calculate optimal routes.

3.2 Research Methods

Graph theory, multi-criteria optimization, and network analysis are applied to model the logistics network and evaluate its efficiency. Network analysis metrics such as degree centrality**,** betweenness centrality, and closeness centrality are used to determine the relative importance of nodes and identify critical transit hubs.

3.3 Mathematical Model of the Logistics Network

The logistics network is modeled as a graph, where nodes represent logistics terminals, ports, and railway stations, and edges represent transport connections between them [3].

The logistics network is expressed through the following mathematical structure:

$$G = (V, E) \quad (1)$$

$V = \{v_1, v_2, \dots, v_n\}$ the set of logistics nodes,

$E = \{e_{ij}\}$ represents the set of transport links between nodes.

Here, i and j represent:

- i— the output node (the node where the cargo starts)
- j— the destination node (the node where the cargo arrives)

Each logistics connection is characterized by transportation cost, time, and logistics risk [4].

Therefore, each connection can be described by the following parameter vector:

$$e_{ij} = (C_{ij}, T_{ij}, R_{ij}) \quad (2)$$

Here:

- C_{ij} — the transportation cost from node i to node j
- T_{ij} — the transportation time
- R_{ij} — the logistics risk

A logistics route is defined as a sequence of connected nodes [5]:

$$P = (v_1, v_2, \dots, v_k)$$

The total cost, time, and risk of a route are calculated as the sum of the corresponding parameters along the selected edges [6]:

$$C(P) = \sum_{(i,j)\in P} C_{ij}, \quad T(P) = \sum_{(i,j)\in P} T_{ij}, \quad R(P) = \sum_{(i,j)\in P} R_{ij} \quad (3)$$

These formulations provide a mathematical basis for evaluating and comparing alternative logistics routes within the network.

3.4 Multi-objective Optimization Model

In multimodal logistics, route selection cannot rely on a single criterion, as minimizing cost may increase time, and minimizing time may raise costs. Therefore, optimization is formulated as a multi-objective problem. Multiple criteria—transportation cost $C(P)$, time $T(P)$, and logistics risk $R(P)$ —are combined in a weighted objective function [7]:

$$F(P) = \alpha C(P) + \beta T(P) + \gamma R(P), \quad \alpha + \beta + \gamma = 1 \quad (4)$$

Here, α, β, γ represent the relative importance of each criterion. The objective is to minimize $F(P)$, achieving a balance among cost, time, and risk.

Pareto Optimization Model

When multiple conflicting criteria exist, a single optimal solution may not exist. The Pareto approach identifies compromise solutions where improving one criterion worsens at least one other [8]. Let X denote the set of all possible routes, and $f(x)$ represent the evaluation function across criteria.The set of Pareto optimal solutions is determined by the following mathematical expression:

$$P^* = \{ x \in X \mid \nexists\, y \in X : f(y) \leq f(x) \wedge f(y) \neq f(x) \} \quad (5)$$

The meanings of the mathematical symbols used in this expression are as follows:

- P^* – represents the set of Pareto optimal solutions. This set includes only the decision alternatives considered most efficient in terms of compromise.
- $x \in X - x$ denotes a possible decision alternative, and X represents the set of all possible decisions.
- $y \in X$ – indicates an alternative decision option.
- $f(x)$ $-$ the function representing the evaluation of decision x according to the objective functions.
- $f(y) \leq f(x)$ $-$ indicates that the y alternative is not worse than the x alternative in all criteria (i.e., it is at least as good or better).
- $\nexists$ $-$ a logical symbol meaning "does not exist." This implies that there is no other solution that is better than x across all criteria.

The Pareto approach identifies compromise solutions where improving one criterion worsens another, supporting evidence-based decision-making and enhancing transport efficiency.

3.5 Network Constraints

The model includes technical and capacity constraints reflecting real-world operational conditions. These constraints reflect real-world logistics operations.

The decision variable used in route selection is defined as follows:

$$x_{ij} = \begin{cases} 1, & \text{if the } i \to j \text{ connection exists} \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

This variable indicates which connections are selected in the logistics network. In this case, the optimization function is written in the following form:

$$\min F = \sum_{i=1}^{n} \sum_{j=1}^{n} (\alpha C_{ij} + \beta T_{ij} + \gamma R_{ij}) x_{ij} \quad (7)$$

In the logistics system, the balance of the cargo flow is expressed by the following equality:

$$\sum_{j=1}^{n} x_{ij} - \sum_{j=1}^{n} x_{ji} = b_i \quad (8)$$

Here, b_i represents the difference between the inflow and outflow of cargo at node i.
In addition, the capacity of logistics links is also considered as a constraint:

$$0 \leq f_{ij} \leq u_{ij} \quad (9)$$

Here,
f_{ij} — actual cargo flow on the link
u_{ij} — maximum capacity of the link.

Application and Analysis of the Model
The proposed mathematical model allows for a comparative analysis of different routes within the logistics system. When several alternative routes exist in the logistics network, their effectiveness is compared based on the values of the objective function.
If two alternative routes P_1 and P_2 exist, the optimal route is determined based on the following comparison:

$$F(P_1) < F(P_2)$$

If this condition is satisfied, route P_1 is considered more efficient.

3.6 Network Centrality and Mathematical Analysis of Logistics Nodes
In evaluating the efficiency of a logistics network, optimizing routes alone is not sufficient. The structural importance of nodes within the network also significantly affects the overall performance of the logistics system. Therefore, centrality indicators from graph theory are used to determine the role of logistics nodes within the network.

One of the main indicators for assessing the importance of a node in a logistics network is degree centrality. This indicator shows how many direct connections a node has with other nodes.
If the logistics network consists of n nodes, the degree centrality of node v_i is defined as follows:

$$C_D(v_i) = \sum_{j=1}^{n} a_{ij} \quad (10)$$

Here,
a_{ij}— is an element indicating the existence of a connection between nodes.

$$a_{ij} = f(x) = \begin{cases} 1, & \text{if the i} \rightarrow \text{j connection exists} \\ 0, & \text{otherwise} \end{cases}$$

This indicator indicates how active a logistics node is within the network.

Intermediate centrality and identification of transit nodes
In a logistics system, some nodes serve as transit points between various routes. Such nodes are called transit centers, and their significance is especially high in international transport corridors.

To identify these nodes, the betweenness centrality indicator is used. If the total number of all possible shortest paths between nodes s and t is denoted by σ_{st} , and the portion of these paths passing through node v_i is expressed as $\sigma_{st}(v_i)$, then the betweenness centrality of the node is defined as follows:

$$C_{B(v_i)} = \sum_{s \neq v_i \neq t} \frac{\sigma_{st}(v_i)}{\sigma_{st}} \quad (11)$$

This indicator allows determining which nodes in the logistics network are more important from a transit perspective.

Closeness Centrality and Logistics Efficiency
One of the important indicators in a logistics system is how quickly a node can reach other nodes. This characteristic is evaluated using the closeness centrality indicator. If $d(v_i, v_j)$ represents the shortest distance between nodes, then the closeness centrality is calculated as follows:

$$C_c(v_i) = \frac{n-1}{\sum_{j=1}^{n} d(v_i, v_j)} \quad (12)$$

A high value of this indicator indicates that the node occupies a strategic position within the logistics system.

3.7 Algorithmic Calculation of the Optimal Route

Determining the optimal route in a logistics network mathematically corresponds to the shortest path problem [1]. To solve this problem, the widely used Dijkstra algorithm from graph theory is applied. The algorithm calculates the minimal weighted distance from the starting node to all other nodes, thereby determining the optimal logistics route [2].

If the weight of each connection in the logistics network is defined as

$$\omega_{ij} = \alpha C_{ij} + \beta T_{ij} + \gamma R_{ij} \quad (13)$$

then the optimal route can be found through the following optimization problem:

$$min \sum_{(i,j) \in P} \omega_{ij} \quad (14)$$

This problem can be solved using various algorithms employed in graph theory [3]. By applying the Dijkstra algorithm, the minimal weighted distances from the starting node to all other nodes are calculated, and the optimal logistics route is determined [2].Based on the proposed model and simulation assumptions, a potential optimal multimodal route can be represented as follows:

Xi'an → Urumqi → Almaty → Aktau → Baku → Tbilisi → Kars → Ankara → Istanbul → Sofia → Budapest → Vienna → Berlin [3,7].

This route represents the main logistics segments of the China–Central Asia–Caspian–South Caucasus–Europe transport corridor and can be considered efficient under the assumptions of the proposed model [3,7].

The multimodal performance of the calculated optimal route segments, highlighting the strategic nodes of Baku and Istanbul, is visualized in Figure 1 [7].

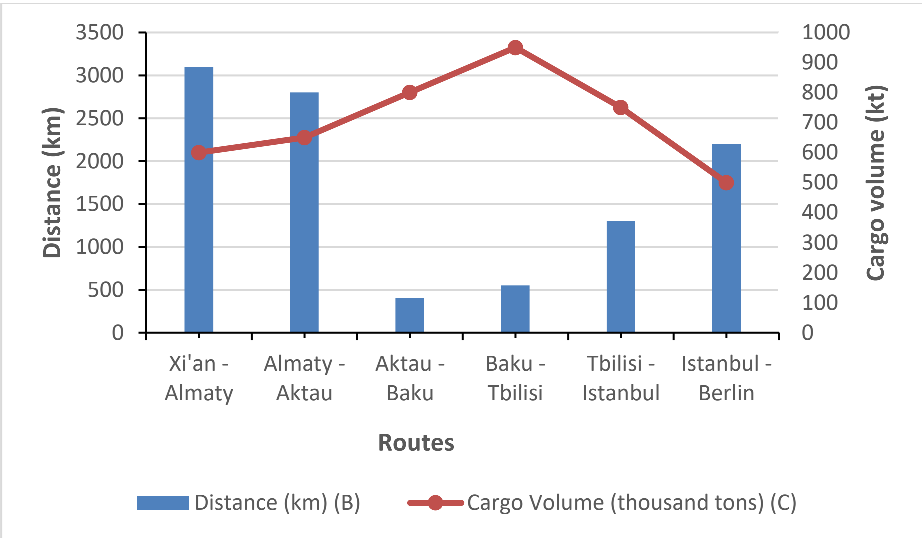

Fig. 1. Comparative Analysis of Distance and Cargo Volume Along Route Segments.

The results in Figure 1 are based on simulated data. Within the scope of the model, the findings suggest that there is no direct proportional relationship between segment distance and cargo intensity [7]. While longer segments such as Xi'an–Almaty and Istanbul–Berlin cover greater distances, higher cargo volumes appear to be concentrated along the Baku–Tbilisi and Tbilisi–Istanbul segments. This may indicate that these segments could function as important strategic nodes within the modeled Middle Corridor network [7,9].

3.8 Application of the Dijkstra Algorithm in the Logistics Network

To calculate the optimal route in the logistics network, the following steps of the Dijkstra algorithm are applied.

Algorithm: Calculation of the Optimal Logistics Route

Input Data

- Graph $G = (V, E)$
- Connection weights ω_{ij}
- Starting node s

The Dijkstra algorithm is applied to compute shortest paths by iteratively updating minimum distances from the source node, enabling the determination of optimal routes in the weighted logistics network.

4. Dynamic and Multimodal Logistics Modeling

4.1 Dynamic Logistics Model

Logistics systems have parameters that change over time. Transportation costs, cargo flows, and logistics risks can vary over specific time intervals. Therefore, dynamic models are used for a more accurate representation of logistics systems.

If logistics parameters are considered as functions of time, the transportation cost can be expressed as:

$$C_{ij}(t)$$

In this case, the overall optimization function is expressed as:

$$F(P,t) = \alpha C(P,t) + \beta T(P,t) + \gamma R(P,t) \quad (15)$$

The dynamic model allows for analyzing the logistics network's performance over different time intervals.

4.2 Mathematical Example

Suppose a logistics network has three main nodes:

$$V = \{A, B, C\}$$

and the connections are characterized by the following parameters:

Table 1. Costs, time, and risk values for connections in the logistics network.

Connection	Cost	Time	Risk
A–B	5	4	2
B–C	3	3	1
A–C	10	2	4

If the importance coefficients are: $\alpha = 0.5,\ \beta = 0.3,\ \gamma = 0.2$
then the weight of each connection is calculated as follows. For example:

$$\omega_{AB} = 0.5 \cdot 5 + 0.3 \cdot 4 + 0.2 \cdot 2$$

$$\omega_{AB} = 2.5 + 1.2 + 0.4 = 4.1$$

Similarly, the weights of the other connections are calculated, and the route with the smallest total sum is considered optimal.

4.3 Structural Analysis of the Logistics Network

Network analysis identifies key transit nodes—Baku, Tbilisi, and Istanbul—as critical for efficient multimodal transport along the East–West corridor. These nodes act as major intersections, enhancing network stability and facilitating cargo movement between Central Asia, the Caspian region, and Europe.

Centrality measures were calculated using standard network analysis tools, modeling the logistics network as a directed graph (Table 2).

Table 2. Centrality measures of key nodes in the East–West multimodal logistics network.

Node	Degree Centrality	Betweenness Centrality	Closeness Centrality	Comment
Baku	0.42	0.61	0.48	Key transit hub, main node for multimodal shipments across the Caspian Sea. High network importance.
Tbilisi	0.31	0.44	0.39	Regional transit node, connecting Baku and Kars routes. High betweenness centrality.
Istanbul	0.46	0.52	0.50	Strategic node in the European segment, high

Node	Degree Centrality	Betweenness Centrality	Closeness Centrality	Comment
				degree and closeness centrality in the network.
Aktau	0.28	0.35	0.33	Critical node for shipments across the Caspian Sea. Moderate centrality.
Almaty	0.30	0.36	0.34	Central Asia transit node, important for regional shipments.
Xi’an	0.25	0.30	0.32	Starting point of the China segment, relatively important in the network.
Urumqi	0.27	0.31	0.33	Intersection node of Central Asia routes, serves a transit function.
Tashkent	0.22	0.28	0.29	Regional node, mainly important for intra-Central Asia shipments.
Batumi	0.20	0.25	0.27	Port node in the South Caucasus segment, regionally significant.
Kars	0.32	0.38	0.36	Main transit node on the Baku–Tbilisi–Kars railway.
Ankara	0.35	0.40	0.38	Logistics hub in the Turkey segment, connecting European routes.
Sofia	0.33	0.37	0.35	Regional node in the European segment, important for Balkan shipments.
Bucharest	0.30	0.34	0.33	Transit node in Eastern Europe, ensures logistics balance.

Node	Degree Centrality	Betweenness Centrality	Closeness Centrality	Comment
Budapest	0.31	0.36	0.34	Central European segment, important for route coordination.
Vienna	0.29	0.33	0.32	Access node to Western European routes, medium network importance.
Berlin	0.34	0.39	0.37	Strategic node in Western Europe, high closeness centrality in the network.

Centrality analysis indicates that Baku and Istanbul serve as the main transit hubs due to their high connectivity and strategic positioning. Nodes with high betweenness centrality play a critical role in ensuring efficient cargo flows across multiple routes, while other nodes primarily maintain regional connectivity within the multimodal transport system. The computational implementation of the model was performed using standard network analysis tools, supporting the evaluation and validation of optimal routes.

4.4 Practical Application of the Model

The proposed model is applied to the East–West Transport Corridor, a key multimodal freight system connecting Asia and Europe. The main transport nodes are located across China, Central Asia, the Caspian region, the South Caucasus, and Europe.

These nodes represent strategic points connecting rail, road, and maritime links, and the logistics network is represented as a graph:

$$V = (v_1, v_2, \dots, v_{18})$$

The main transport segments include:

- China – Central Asia railway routes
- Ferry transport across the Caspian Sea
- Azerbaijan & Georgia railway infrastructure
- Baku–Tbilisi–Kars railway line
- European transport network via Turkey

Graph Structure of the Logistics Network:

China: Xi’an → Urumqi
Central Asia: Urumqi → Almaty → Tashkent → Aktau
Caspian Sea: Aktau → Baku (maritime)
South Caucasus: Baku → Ganja → Tbilisi → Batumi
South Caucasus–Turkey: Tbilisi → Kars (Baku–Tbilisi–Kars railway)
Europe: Kars → Ankara → Istanbul → Sofia → Bucharest → Budapest → Vienna → Berlin

This representation highlights the integration of rail, road, and maritime transport within a unified logistics system.

4.5 Azerbaijan and Global Energy Logistics

The East–West transport corridor is important not only for goods transportation but also for delivering energy resources to global markets. Due to the rich energy reserves of the Caspian region, transporting these resources to Europe and beyond is a strategic direction in international logistics.

Azerbaijan holds a key position thanks to its energy fields in the Caspian Sea and its developed transport infrastructure, acting as a major transit and export hub. Energy transport mainly includes oil and natural gas via:

- Baku–Tbilisi–Ceyhan (BTC) oil pipeline
- Baku–Supsa oil pipeline
- Southern Gas Corridor
- Caspian Sea tanker transport

These systems support energy supply to Europe and enhance global energy security.

To integrate energy logistics into the multimodal logistics model, an additional parameter is incorporated into the network model. The energy flow is expressed as: E_{ij}, where E_{ij} represents the volume of energy resources transported between nodes i and j.

Accordingly, the optimization function is extended as follows:

$$F(P) = \alpha C(P) + \beta T(P) + \gamma R(P) + \delta E(P) \quad (16)$$

Here:

- $C(P)$ – transportation cost
- $T(P)$ – transportation time
- $R(P)$ – logistics risk
- $E(P)$ – economic significance of energy transportation
- The δ coefficient represents the role of energy logistics in the optimization process.

This model integrates general logistics operations with energy transportation flows and allows a more precise assessment of the strategic significance of the transport corridor.

Digital Logistics and Intelligent Transportation Systems

Digital technologies enable real-time monitoring and optimization in logistics systems.

Key components include:

- IoT sensors
- GPS and satellite systems
- Blockchain platforms
- AI-based optimization
- Big Data analytics

In this case, the parameters of the logistics model can be expressed as:

$C_{ij}(t), T_{ij}(t), R_{ij}(t)$

Here, t is the time parameter.

The optimization function is expressed as follows:

$$F(P,t) = \alpha C(P,t) + \beta T(P,t) + \gamma R(P,t)$$

This approach allows modeling the operation of the logistics system in a dynamic environment.

5 Fuzzy Logistics Model

In practice, transportation costs, time, and risk are uncertain due to weather, political risks, delays, and market fluctuations. A fuzzy logic approach allows modeling these uncertainties, accommodating imprecise or incomplete information [10].

5.1 Mathematical Representation of Fuzzy Sets

A fuzzy set is defined as:

$$A = \{ (x, \mu_A(x)) \mid x \in X \}$$

where

$\mu A(x)$ is the membership function, indicating the degree to which an element belongs to the set, with

$$0 \le \mu_A(x) \le 1$$

In a logistics system, parameters such as transportation cost and time can be considered fuzzy variables. For example,

$$\tilde{C}_{ij} = \left(C_{ij}^{min}, C_{ij}^{med}, C_{ij}^{max}\right) \quad (17)$$

is referred to as a triangular fuzzy number.

Fuzzy Logistics Parameters

In a multimodal logistics network, the parameters of connections can be represented as a fuzzy vector:

$$e_{ij} = \left(\tilde{C}_{ij}, \tilde{T}_{ij}, \tilde{R}_{ij} \right) \quad (18)$$

where

$\tilde{C}_{ij}$ – fuzzy transportation cost

$\tilde{T}_{ij}$ – fuzzy transportation time

$\tilde{R}_{ij}$ – fuzzy logistics risk

Fuzzy Optimization Function

In this case, the logistics optimization function can be written as:

$$\tilde{F}(P) = \alpha\tilde{C}(P) + \beta\tilde{T}(P) + \gamma\tilde{R}(P) \quad (19)$$

where

$$\tilde{C}(P) = \sum_{(i,j)\in P} \tilde{C}_{ij}$$

$$\tilde{T}(P) = \sum_{(i,j)\in P} \tilde{T}_{ij}$$

$$\tilde{R}(P) = \sum_{(i,j)\in P} \tilde{R}_{ij}$$

This approach enables modeling uncertainty in logistics parameters.

Fuzzy Weighted Graph Model

A fuzzy logistics network can be represented as:

$$G\_f = \left(V, E, \widetilde{W}\right) \quad (15)$$

where

- V — set of nodes
- E— set of edges
- $\widetilde{W}$— fuzzy weight matrix

The weight of an edge is defined as:

$$\widetilde{\omega}_{ij} = \alpha\tilde{C}_{ij} + \beta\tilde{T}_{ij} + \gamma\tilde{R}_{ij} \quad (20)$$

Fuzzy Dijkstra Algorithm

The optimal route in the logistics network is determined by the following optimization problem:

$$min \sum_{(i,j)\in P} \widetilde{\omega}_{ij} \quad (21)$$

This problem is solved using fuzzy graph algorithms.

5.2 Digital Logistics and IoT-Based Data Models

In digital logistics systems, logistics parameters can be measured in real time using sensor technologies. IoT sensors transmit information about container temperature, location, and transport status to a central logistics platform.

These data can be represented as a time-dependent function:

$$x_{ij}(t)$$

where

$x_{ij}(t)$— represents the flow of goods over a logistics connection at a given point in time.

Digital Logistics Optimization Model

Logistics optimization on digital platforms can be expressed as:

$$minF = \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{ij}(t) x_{ij}(t) \quad (22)$$

where

$$\omega_{ij}(t) = \alpha C_{ij}(t) + \beta T_{ij}(t) + \gamma R_{ij}(t) \quad (23)$$

This model demonstrates real-time optimization in the logistics network.

5.3 Fuzzy Risk Model

Logistics risks can be represented using fuzzy probability distributions.

Risk Function:

$$R_{ij} = P_{ij} \times L_{ij} \quad (24)$$

where

- P_{ij}— probability of the event
- L_{ij}— potential loss

Fuzzy Risk Representation:

$$\tilde{R}_{ij} = \left(R_{ij}^{min}, R_{ij}^{med}, R_{ij}^{max}\right) \quad (25)$$

This approach allows incorporating uncertainty in risk assessment within logistics optimization.

Fuzzy Analysis of the Azerbaijan Logistics Node

Azerbaijan, particularly through the Port of Baku, plays the role of a logistics hub in the Caspian region. The logistics importance of the Baku node can also be evaluated using a fuzzy centrality indicator.

$$\tilde{C}_B(v_i) = \sum_{j=1}^{n} \tilde{a}_{ij} \quad (26)$$

This indicator measures the logistics significance of a node under conditions of fuzzy or uncertain connections within the network.

Conclusion

This study proposes a multi-criteria mathematical model based on graph theory for analyzing and optimizing multimodal logistics networks [4,5]. The model represents logistics nodes and transport links in a unified structure, simultaneously considering transportation cost, transit time, and logistics risks. Applied to the East–West Transport Corridor, the multi-objective problem was converted into a weighted single-objective function, and graph-theoretic algorithms were used to identify optimal routes. Analysis highlighted the strategic significance of key nodes, particularly Azerbaijan, as a major transit hub integrating regional energy and logistics infrastructure into international trade.

The multi-criteria approach improves route selection compared to traditional models by balancing cost, time, and risk more effectively [6,7]. Practical implications include enhanced planning and management of international logistics, cost reduction, and risk evaluation.

The empirical validation of the model, as visualized in Figure 1, demonstrates that the Baku–Tbilisi–Istanbul axis serves as the high-intensity core of the Middle Corridor. This aligns with the centrality measures calculated in the study, suggesting that strategic infrastructure investments in these nodes may play an important role in improving the efficiency and reliability of the logistics network.

Future Research Directions

Future studies may integrate the model with real-time data from IoT sensors, satellite monitoring, and big data analytics for more accurate and dynamic network modeling. Incorporating AI and machine learning could enhance route planning and risk forecasting. Additionally, evaluating the economic and environmental impacts of the Middle Corridor is recommended. Model-based estimations suggest that optimizing multimodal networks along this corridor may potentially reduce transport costs and transit time, highlighting the practical value of multi-criteria optimization in logistics systems.

Acknowledgments. The author sincerely thanks colleagues and the academic community for their support in accessing scientific sources and conducting the research. The use of scientific literature and international studies has contributed to a more comprehensive analysis of the topic.

Disclosure of Interests. The author declares no competing interests.

References

1. E. W. Dijkstra: A note on two problems in connexion with graphs. *Numerische Mathematik* 1(1), 269–271 (1959)
2. R. K. Ahuja, T. L. Magnanti, J. B. Orlin: *Network flows: Theory, algorithms, and applications*. Prentice Hall, New Jersey (1993)
3. J. P. Rodrigue, C. Comtois, B. Slack: *The geography of transport systems*, 2nd edn. Routledge, New York (2020)
4. M. E. Porter: *Competitive advantage: Creating and sustaining superior performance*. Free Press, New York (1998)
5. T. Notteboom, J. P. Rodrigue: Port regionalization: Towards a new phase in port development. *Maritime Policy & Management* 32(3), 297–313 (2005)
6. D. A. Hensher, K. J. Button: *Handbook of transport modelling*. Elsevier, Oxford (2008)
7. United Nations Conference on Trade and Development: *Review of maritime transport 2022*. United Nations, New York (2022)
8. United Nations Economic and Social Commission for Asia and the Pacific: *Enhancing connectivity of the Trans-Caspian International Transport Route*. United Nations, Bangkok (2021)
9. F. Guliyev: Transport corridors and regional integration in the South Caucasus. *Eurasian Geography and Economics* 61(4–5), 512–530 (2020)
10. L. A. Zadeh: Fuzzy sets. *Information and Control* 8(3), 338–353 (1965)