Intelligent Control of Transit Cargo Flows in the Baku Logistics Hub of the East–West Transport Corridor

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Abstract. Efficient management of transit cargo flows is one of the key challenges in modern transport logistics, especially for international transport corridors connecting Asia and Europe. Azerbaijan plays a strategic role in the East–West transport corridor, where the Baku Logistics hub acts as an important multimodal transport node integrating maritime, railway, road and air cargo transportation. In this study, a mathematical model of the transport network of the Baku Logistics hub is proposed for the analysis and optimization of transit cargo flows. The transport system is represented as a directed graph in which nodes correspond to logistics centers and transport hubs, while edges represent transport routes between them. The objective of the model is to determine optimal routes for cargo transportation based on transit time and network conditions. Simulation experiments were conducted in the MATLAB environment to evaluate the behavior of the transport control system under different operational scenarios, including transport delays and infrastructure disruptions. The proposed model can also be used to analyze the stability of transport networks and to evaluate alternative logistics routes under varying operational conditions. The results demonstrate that intelligent control of transport routes allows more efficient distribution of cargo flows and improves the reliability of transit transportation within the East–West corridor. The proposed approach can be applied to the development of intelligent transport management systems for multimodal logistics networks.

Keywords: transport logistics, graph modeling, intelligent transport systems, cargo flow optimization, multimodal transport, East–West corridor.

1. Introduction

The rapid development of international trade and economic globalization has significantly increased the importance of efficient transport and logistics systems. Modern supply chains depend on reliable transport infrastructure that ensures the timely movement of goods between production centers and consumer markets. As a result, international transport corridors have become an essential element of the global logistics network [10]. These corridors integrate different modes of transport and create continuous routes that facilitate large-scale cargo transportation between continents [1]. One of the most important directions of international cargo transportation is the East–West transport corridor connecting the countries of Central Asia with European markets. This corridor provides an alternative route for cargo flows between Asia and Europe and plays a significant role in the development of regional trade and economic cooperation. Compared to traditional maritime routes, the East–West corridor offers the possibility of reducing transportation time and improving the flexibility of logistics operations. However, the operation of such corridors requires the coordination of different transport systems and efficient management of cargo flows [2].

The East–West corridor includes a complex multimodal transport system that integrates maritime, railway, road and air transport. Multimodal transport systems allow cargo to be transported using different modes of transportation within a single logistics chain. Such systems increase the efficiency of cargo delivery but at the same time create additional challenges related to the coordination of transport operations, route planning and infrastructure capacity management. Therefore, the development of intelligent transport control systems becomes an important task for modern logistics networks.

Azerbaijan occupies a strategically important position in the East–West transport corridor due to its geographical location between Central Asia and Europe. The country serves as a transit hub that connects the Caspian region with the South Caucasus and further with European transport networks. In recent years Azerbaijan has actively developed its transport infrastructure, including ports, railway lines and logistics centers, in order to strengthen its role in international transit transportation [3].

One of the key elements of this transport system is the Baku Logistics hub. The hub integrates several important transport facilities including the Baku International Sea Trade Port (Alat), railway connections with neighboring countries and air cargo transportation through international airports [4]. The port of Baku plays a crucial role in connecting maritime routes across the Caspian Sea with railway transport corridors leading to Georgia, Turkey and European countries. As a result, the Baku Logistics hub acts as an important multimodal node that supports the efficient movement of cargo flows between Asia and Europe [5].

The increasing complexity of multimodal transport systems requires the application of advanced information technologies and intelligent transport management methods. Intelligent transport systems allow transport operators to monitor infrastructure conditions, manage cargo flows, analyze transport routes and reduce delays caused by congestion or infrastructure disruptions. The use of digital technologies and mathematical modeling methods can significantly improve the efficiency of logistics networks and support decision-making processes in transport management.

Mathematical modeling plays an important role in the analysis of transport systems and the optimization of cargo flows. Graph-based models are widely used to represent transport networks because they allow the structure of the network to be described in a formal mathematical form. In such models, transport nodes such as ports, logistics centers and terminals are represented as vertices of a graph, while transport connections between them are represented as edges. This representation makes it possible to analyze connectivity, determine optimal transport routes and evaluate the influence of different factors on the performance of the transport network.

In this study, a mathematical model of an intelligent transport control system for the Baku Logistics hub is proposed. The model represents the transport network as a directed graph and allows the analysis and optimization of transit cargo flows within the East–West transport corridor. The proposed approach makes it possible to determine optimal cargo transportation routes and to evaluate the impact of different operational conditions such as transport delays and infrastructure disruptions. Simulation experiments are carried out to analyze the performance of the transport control system and to demonstrate the advantages of intelligent route optimization for multimodal transport networks.

2. Transport Network of the Baku Logistics Hub

The development of international transport corridors requires the integration of different modes of transportation and the creation of efficient logistics hubs that support multimodal cargo transportation. One of the important elements of the East–West transport corridor is the Baku logistics hub, which serves as a key transit node connecting Central Asia with the countries of the South Caucasus and Europe. Due to its geographical location and developed transport infrastructure, Azerbaijan plays a significant role in facilitating international cargo transportation across the region.

The Baku Logistics hub integrates several transport facilities including the Baku International Sea Trade Port located in Alat, railway transport infrastructure, road transport connections and air cargo transportation through Baku international airports. The integration of these transport systems allows the efficient organization of multimodal cargo transportation and supports the development of international transit routes between Asia and Europe.

Maritime transport plays an important role in connecting the Baku Logistics hub with Central Asian countries through the Caspian Sea. Ports such as Aktau and Kuryk in Kazakhstan are connected with the Baku Port by maritime shipping routes. These maritime routes form an essential part of the transport corridor and allow cargo to be transported from Central Asia to the South Caucasus. After arriving at the Baku Port, cargo can be transferred to railway or road transport and further delivered to neighboring countries.

Railway transport represents another key component of the East–West transport corridor. The railway infrastructure connecting Azerbaijan with Georgia and Turkey provides an efficient land transport route that allows cargo to be transported further toward European markets. The Baku–Tbilisi–Kars railway line plays a particularly important role in this process, as it creates a direct railway connection between the Caspian region and the European transport network [5]. This railway corridor significantly improves the efficiency of cargo transportation and reduces transit time between Asia and Europe.

Road transport also contributes to the operation of the logistics network by providing flexible cargo delivery between logistics centers and transport terminals. Road transport is often used for short-distance transportation and for connecting railway stations, ports and airports within the logistics system. The combination of railway and road transport ensures the continuity of cargo flows within the transport network.

Air cargo transportation represents an additional component of the multimodal transport system. Air transport is typically used for high-value or time-sensitive cargo that requires fast delivery. The presence of air cargo terminals in the Baku Logistics hub enhances the flexibility of the transport system and allows the integration of air transport with other modes of transportation.

The structure of the transport network of the Baku Logistics hub is illustrated in Fig. 1. The figure presents the main logistics nodes and transport routes connecting Central Asia with European markets through Azerbaijan. The network includes maritime routes across the Caspian Sea, railway corridors connecting Azerbaijan with Georgia and Turkey, and air cargo routes linking logistics centers with international airports. This multimodal transport network forms the basis for the organization and management of transit cargo flows in the East–West transport corridor.

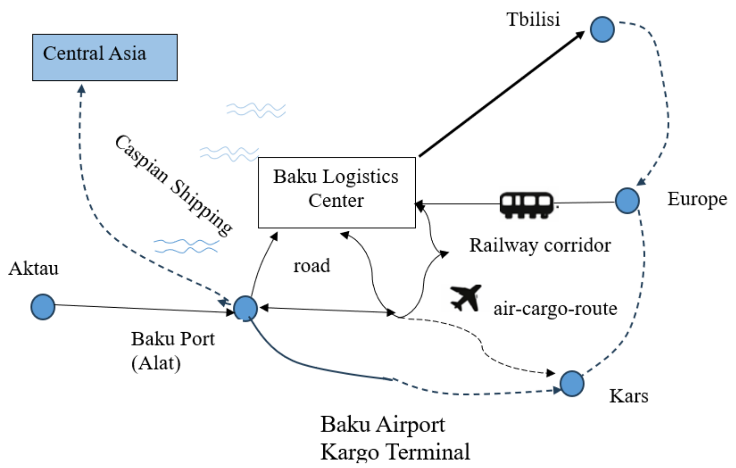


Fig. 1.Transport network of the Baku logistics hub in the East–West transport corridor

The analysis of the transport network structure shows that the Baku Logistics hub plays a crucial role in coordinating cargo transportation between different regions. Efficient management of this network requires the use of advanced control systems that can analyze transport routes, evaluate transit times and determine optimal cargo transportation paths. Therefore, the development of mathematical models describing the structure and behavior of the transport network becomes an important task for improving the efficiency of international transport corridors.

In order to analyze the operation of the transport network and to optimize cargo transportation routes, it is necessary to develop a formal mathematical representation of the transport system. In the following section, the transport network of the Baku logistics hub is represented as a graph-based mathematical model that allows the analysis of cargo flows and the determination of optimal transportation routes under different operational conditions.

3. Mathematical model of the transport network

Efficient management of cargo transportation in multimodal logistics networks requires the development of mathematical models that describe the structure and operation of the transport system [7]. Mathematical modeling allows researchers and transport planners to analyze transport connectivity, evaluate transit times and determine optimal cargo transportation routes. In this study, the transport network of the Baku Logistics hub is represented as a directed weighted graph.

The transport network of the Baku logistics hub connecting Central Asia with Europe through multimodal transport routes is presented in Fig. 1.

$$G = (V, E) \tag{1}$$

In (1) G represents the set of transport nodes and E represents the set of transportconnections between nodes.

Transport nodes correspond to important elements of the logistics network such as ports, logistics centers, railway terminals and transport hubs. In the considered transport network the main nodes include Aktau port, Baku Port (Alat), the Baku Logistics center, Tbilisi railway terminal, Kars railway terminal and European logistics hubs. These nodes form the key points of the transport corridor that connects Central Asia with Europe.

Transport routes between nodes are represented as edges of the graph. Each edge corresponds to a transport connection between two nodes and can represent maritime transport, railway transport, road transport or air cargo transportation. The use of a graph representation allows the structure of the transport network to be analyzed using well-known methods of graph theory and network optimization.

Each edge of the graph is assigned a weight that represents the transportation cost or transit time between two nodes. In this study, the weight of an edge corresponds to the average transportation time required for cargo to move between the corresponding transport nodes. Let the weight of the edge connecting nodes i and j be denoted as ω_{ij}. The weight matrix of the transport network can therefore be represented as

$$W=[\omega_{ij}]$$

where ω_{ij} represents the transit time between nodes i and j.

The main objective of the transport control system is to determine the optimal route for cargo transportation through the transport network. The optimal route is defined as the route that minimizes the total transit time required to deliver cargo from the origin node to the destination node. The optimization problem can be formulated as

$$\min \sum_{(i,j)\in E} \omega_{ij}\, x_{ij}$$

where x_{ij} is a decision variable defined as

$$x_{ij} = \begin{cases} 1, \text{ if the route between nodes i and j is used,} \\ 0, \text{ otherwise.} \end{cases}$$

The above formulation represents the problem of finding the shortest path in a transport network. This approach allows the determination of optimal cargo transportation routes under given network conditions.

In real transport systems, however, the transit time between nodes may vary depending on operational conditions such as infrastructure congestion, weather conditions, port delays or railway disruptions. In order to take these factors into account, the edge weights of the transport network can be expressed as time-dependent values

$$\omega_{ij}(t) = T_{ij} + D_{ij}$$

where T_{ij} represents the base transportation time between nodes i and j, and D_{ij} represents additional delays that depend on the current state of the transport network.

The use of time-dependent edge weights allows the development of intelligent transport control systems that dynamically adapt cargo routes according to the operational conditions of the transport network. Such systems can monitor the state of transport infrastructure and update optimal routes when disruptions occur.

The graph-based mathematical model described above provides a formal representation of the transport network of the Baku logistics hub and creates the basis for further analysis of cargo transportation processes. Using this model, it is possible to simulate the operation of the transport system, evaluate the influence of different disruptions on cargo flows and determine optimal routes for cargo transportation in the East–West transport corridor.

In the next section, simulation experiments are carried out in the MATLAB environment in order to analyze the behavior of the proposed transport control model and evaluate its efficiency under different operational scenarios.

Each edge of the transport network is assigned a weight representing the estimated transit time between transport nodes. These values were calculated based on publicly available route distances and typical transportation speeds for maritime and railway transport in the East–West corridor. The parameters used in the simulation model are presented in Table 1.

Table 1. Estimated transit times used in the transport network model

Edge	Distance (km)	Transport mode	Transit time (h)
Aktau – Baku Port	441	Maritime ferry	24
Baku Port – Baku Logistics	70	Road transport	2
Baku Logistics – Tbilisi	490	Railway transport	11
Tbilisi – Kars	298	Railway transport	7
Kars – Istanbul Hub	1418	Railway transport	24
Baku Logistics – Poti	693	Railway / Road	15
Poti – Istanbul Hub	1320	Railway / Road	22

The estimated transit times presented in Table 1 were used as edge weights in the graph representation of the transport network and were applied in the simulation experiments described in the following section.

4. Simulation Experiments

4.1. Experiment 1: Normal operating conditions

The first experiment analyzes the transport network under normal operating conditions. The edge weights represent the average transit time between transport nodes. The shortest path algorithm implemented in MATLAB was used to determine the optimal cargo transportation route from Aktau to the European logistics hub [8]. The simulation results show that the optimal route is Aktau – Baku Port – Baku Logistics – Tbilisi – Kars – Europe Hub. The total transit time for this route is 68 hours. The obtained transport network configuration is illustrated in Fig. 2**.**

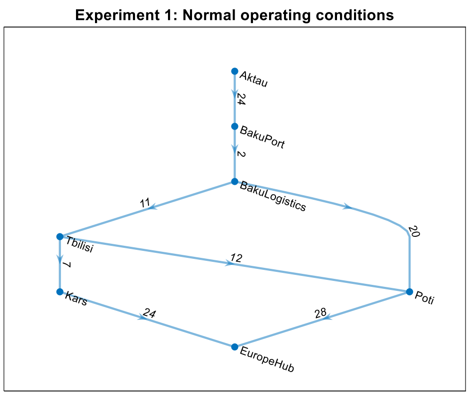
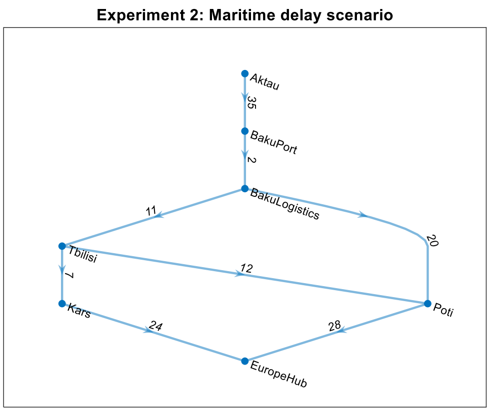


Fig. 2. Optimal cargo transportation route in the Baku logistics network under normal operating conditions.

4.2. Experiment 2: Maritime delay scenario

In the second experiment, a delay on the maritime route between Aktau and Baku Port was simulated. The weight of the corresponding edge was increased from 24 h to 35 h in order to represent unfavorable weather conditions or congestion in the Caspian shipping segment. The shortest path algorithm was then applied again to determine the optimal cargo transportation route. The simulation results show that the selected route remained unchanged and continued to pass through the nodes Aktau – Baku Port – Baku Logistics – Tbilisi – Kars – Europe Hub. However, the total transit time increased from 68 h to 79 h**.** This result demonstrates the significant influence of delays in the maritime segment on the overall efficiency of cargo transportation in the East–West transport corridor. The corresponding transport network configuration is presented in Fig. 3**.**



Fig,3. Optimal cargo transportation route under maritime delay conditions.

4.3. Experiment 3: Railway disruption scenario

In the third experiment, a disruption of the railway connection between Tbilisi and Kars was simulated. This scenario represents infrastructure maintenance, technical failure, or other operational restrictions in the railway corridor. In the graph model, the transit time of the corresponding edge was increased from 7 hours to 1000 hours**,** making this route practically unavailable. The shortest path algorithm was then applied to determine an alternative transportation route. The simulation results show that the intelligent transport control system automatically selected the route Aktau – Baku Port – Baku Logistics – Poti – Europe Hub. The total transit time for the new route is 74 hours (Fig. 4). This experiment demonstrates the ability of the proposed control system to maintain cargo transportation even in the presence of railway disruptions.

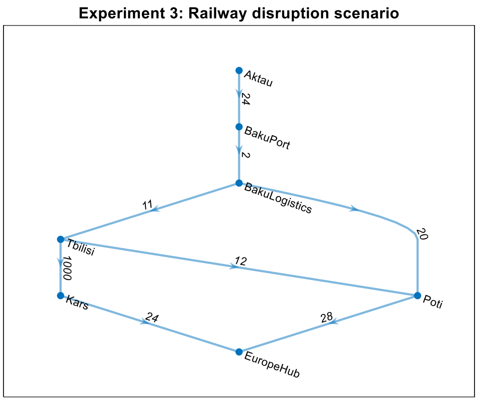


Fig. 4. Alternative cargo transportation route under railway disruption conditions.

4.4. Experiment 4: Static vs intelligent adaptive routing

In the fourth experiment, the performance of static route planning was compared with intelligent adaptive routing. Under normal operating conditions, the shortest path algorithm selected the route Aktau – Baku Port – Baku Logistics – Tbilisi – Kars – EuropeHub with a total transit time of 68 hours. After this initial route selection, disturbed conditions were introduced in the transport network. The maritime route between Aktau and Baku Port was delayed by increasing its transit time from 24 hours to 35 hours, and the railway connection between Tbilisi and Kars was assumed to be disrupted by increasing its weight to 1000 hours.

In the static routing approach, the initially selected route remained unchanged, which increased the total transit time to 1072 hours. In contrast, the intelligent adaptive routing system recalculated the route according to the updated network conditions and selected the alternative path Aktau – Baku Port – Baku Logistics – Poti – Europe Hub with a total transit time of 85 hours (Fig. 5). This experiment demonstrates the significant advantage of intelligent transport control systems in maintaining efficient cargo transportation under dynamic operational conditions.

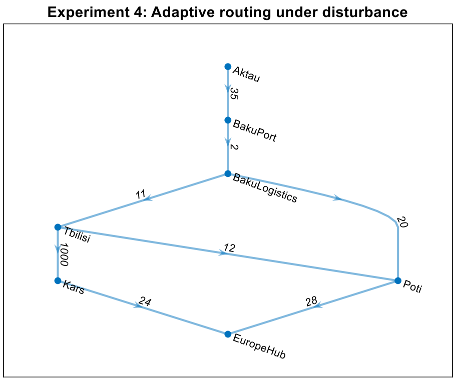


Fig. 5. Transport network under combined disturbance conditions and adaptive routing

5. Results and Discussion

The results obtained from the simulation experiments allow the evaluation of the performance of the proposed transport network model and the intelligent transport control system [9]. The experiments demonstrate how different operational conditions influence route selection and the overall transit time within the transport network of the Baku logistics hub.

Under normal operating conditions, the shortest path algorithm identifies the route Aktau – Baku Port – Baku Logistics – Tbilisi – Kars – Europe Hub as the optimal cargo transportation path. The total transit time for this route is 68 hours, which represents the baseline scenario for the transport network. This route corresponds to the primary railway corridor connecting Azerbaijan with Georgia and Turkey, which plays an important role in the East–West transport corridor.

In the second experiment, the maritime segment between Aktau and Baku Port was affected by a simulated delay. This scenario reflects possible operational disturbances such as unfavorable weather conditions or congestion in the Caspian Sea shipping routes. The results show that although the optimal route remained unchanged, the total transit time increased from 68 hours to 79 hours. This result indicates that delays in the maritime segment have a noticeable impact on the efficiency of cargo transportation across the corridor.

The third experiment analyzed the effect of railway disruption between Tbilisi and Kars. When this railway segment became unavailable, the transport control system automatically identified an alternative route through Poti. The new route Aktau – Baku Port – Baku Logistics – Poti – Europe Hub resulted in a total transit time of 74 hours. Although this route is slightly longer than the baseline scenario, it allows cargo transportation to continue even when a critical railway segment is disrupted.

The fourth experiment compared static route planning with intelligent adaptive routing under combined disturbance conditions. In the static routing approach, the initially selected route remained unchanged despite disruptions in the transport network, which resulted in a dramatic increase in transit time to 1072 hours. In contrast, the intelligent routing system dynamically recalculated the optimal route and selected the alternative path through Poti with a transit time of 85 hours. This result clearly demonstrates the advantage of intelligent transport control systems in maintaining efficient cargo transportation under dynamic operational conditions.

Table 2. Simulation results for different transport network scenarios

Experiment	Scenario	Optimal route	Transit time (h)
1	Normal conditions	Aktau–Baku Port–Baku Logistics–Tbilisi–Kars–Europe Hub	68
2	Maritime delay	Aktau–Baku Port–Baku Logistics–Tbilisi–Kars–Europe Hub	79
3	Railway disruption	Aktau–Baku Port–Baku Logistics–Poti–Europe Hub	74
4	Adaptive routing	Aktau–Baku Port–Baku Logistics–Poti–Europe Hub	85

6. Conclusion

This study presents a graph-based model of a transport network for the analysis and optimization of transit cargo flows within the East–West transport corridor. The proposed model represents the multimodal logistics network of the Baku logistics hub as a directed graph in which transport nodes correspond to logistics centers and transport terminals, while edges represent transportation routes between them. The weights of the edges correspond to the estimated transit times between nodes and are used to determine optimal cargo transportation routes.

A series of simulation experiments was conducted in the MATLAB environment in order to evaluate the performance of the proposed transport network model. The experiments analyzed several operational scenarios including normal operating conditions, maritime delays in the Caspian Sea segment, railway disruptions in the Tbilisi–Kars corridor, and adaptive routing under combined disturbance conditions.

The results of the simulation experiments demonstrate that the proposed model is capable of effectively representing the structure and operational behavior of the transport network. Under normal conditions, the optimal cargo transportation route follows the railway corridor through Tbilisi and Kars with a total transit time of 68 hours. However, when disruptions occur in the transport infrastructure, the intelligent transport control system is able to identify alternative transportation routes and maintain the continuity of cargo flows.

The comparison between static route planning and intelligent adaptive routing shows that the use of dynamic routing algorithms significantly improves the resilience of the transport network. In disrupted conditions, the adaptive routing mechanism successfully identifies alternative paths that minimize transit time and prevent excessive delays in cargo transportation.

The proposed approach can be used as a basis for the development of intelligent transport management systems in multimodal logistics networks. The model can also be extended by incorporating additional factors such as transport costs, cargo volumes, and real-time traffic information. Future research may focus on the integration of real-time data sources and advanced optimization algorithms for improving the efficiency and reliability of international transport corridors.

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