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ORIGINAL

Analysis of the use of artificial intelligence in the management of logistics processes: Approaches and benefits

Análisis del uso de la inteligencia artificial en la gestión de procesos logísticos: efoques y beneficios

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ABSTRACT

This study explores artificial intelligence (AI) applications to improve logistics within the Belt and Road Initiative's Middle Corridor, focusing on Ukraine amid geopolitical disruptions. Its objective is to quantify AI's impact on delivery times, inventory costs, fuel consumption, and network resilience in this complex region. Employing a mixed-method approach, the research combines Social Network Analysis (SNA) to identify key nodes and bottlenecks with simulation modelling based on empirical data from 2019 to 2023, including GPS tracking and port metrics. Results show AI integration reduces delivery times by 11,7 %, cuts inventory holding costs by 16,3 %, and lowers fuel consumption by 9,2 %. SNA reveals enhanced connectivity and efficiency at critical hubs such as Kyiv and Odesa, strengthening Ukraine's strategic logistics role. The study concludes that AI-driven optimizations significantly boost corridor efficiency, resilience, and sustainability. It recommends future work on real-time data integration and broader AI applications to support adaptive, greener supply chains across politically sensitive trade routes.

Keywords: Data Management; Digital Technologies; Logistics Automation; Intelligent Systems; Supply Chain Optimization.

RESUMEN

Este estudio explora las aplicaciones de la inteligencia artificial (IA) para mejorar la logística dentro del Corredor Medio de la Iniciativa de la Franja y la Ruta, con un enfoque especial en Ucrania en medio de las perturbaciones geopolíticas. Su objetivo es cuantificar el impacto de la IA en los tiempos de entrega, los costos de inventario, el consumo de combustible y la resiliencia de la red en esta región compleja. Empleando un enfoque mixto, la investigación combina el Análisis de Redes Sociales (ARS) para identificar nodos clave y cuellos de botella con modelado por simulación basado en datos empíricos desde 2019 hasta 2023, incluyendo seguimiento por GPS y métricas portuarias. Los resultados muestran que la integración de la IA reduce los tiempos de entrega en un 11,7 %, disminuye los costos de mantenimiento de inventario en un 16,3 % y reduce el consumo de combustible en un 9,2 %. El ARS revela una mayor conectividad y eficiencia en hubs críticos como Kyiv y Odesa, fortaleciendo el papel estratégico logístico de Ucrania. El estudio concluye que las optimizaciones impulsadas por IA aumentan significativamente la eficiencia, resiliencia y sostenibilidad del corredor, recomendando futuras investigaciones centradas en la integración de datos en tiempo real y aplicaciones ampliadas de IA para apoyar cadenas de suministro adaptativas y más ecológicas en rutas comerciales políticamente sensibles.

Palabras clave: Gestión de Datos; Tecnologías Digitales; Automatización Logística; Sistemas Inteligentes; Optimización de la Cadena de Suministro.

INTRODUCTION

The efficient functioning of supply chain networks and international trade relies fundamentally on effective logistics management. Efficient logistics operations are essential for companies to remain competitive and profitable in today's global market, where countries and businesses depend heavily on the seamless movement of goods across borders.[1] Optimal resource allocation, waste reduction, and reduced disruptions characterize high-performing logistics systems, ensuring the timely, cost-efficient, and reliable transportation of goods from suppliers to consumers.[2,3] However, managing contemporary logistics networks has become increasingly challenging due to the growing complexity of globalized supply chains.[4]

The Belt and Road Initiative (BRI), launched in 2013, stands as one of the world's most significant infrastructure undertakings, connecting diverse economies across Asia, Europe, Africa, and Latin America via a series of trade corridors.[5] The Middle Corridor, spanning from Europe to Central Asia, occupies a strategic position in reshaping international trade dynamics. Artificial intelligence (AI) has emerged as a transformative tool in this sector, enhancing decision-making and predictive capabilities through advanced data analytics.[6] Predictive analytics driven by AI enables logistics managers to anticipate market, weather, and global events, assisting in planning for potential delays and minimizing risk exposure.[7] AI technologies are, therefore, poised to make transportation networks faster, more reliable, and safer.

Academic research and industry practice increasingly emphasize the integration of AI into logistics management, responding both to the complexity of modern logistics and the rising demand for efficiency, transparency, and supply chain resilience.[8,9,10,11] Large-scale projects such as the BRI and the Middle Corridor are exerting transformative influence over the movement of goods globally. Against this backdrop, the present study uses simulation and social network analysis (SNA) to examine the effects of AI-driven strategies on logistics network performance, with particular attention to optimizing hub connectivity, route efficiency, and operational resilience within the Middle Corridor.

Artificial intelligence (AI) facilitates improved decision-making and rapid adaptation to evolving market conditions. Machine learning including deep learning as a key subset along with predictive analytics, intelligent automation, and natural language processing (NLP), contribute to reducing logistical delays by identifying patterns in large datasets and generating accurate forecasts.[12,13] AI-based demand forecasting systems analyze historical purchase data, market trends, and external factors to predict customer demand, enabling logistics managers to optimize inventory levels and minimize excess stock.[14,15]

Koller et al.[16] studied the effects of EU regulatory frameworks on Ukraine's rail industry, showing transportation networks improve when AI-driven planning and clear regulatory policies are implemented. Benchmarking in logistics also enhances competitiveness and operational efficiency.[17] Abduljabbar et al.[18] highlight AI's role in optimizing transportation routes. AI systems employ real-time data such as traffic, weather, and route history to select the most efficient shipment paths.[19] Machine learning algorithms dynamically adjust routes to avoid delays caused by adverse weather, traffic, or road closures.[20] AI continuously integrates diverse data sources including market events and weather forecasts to manage risks.[21] Yurko et al.[22] emphasize Ukraine's necessity for innovation and resource efficiency to sustain economic growth.

AI-enabled inventory management systems improve demand prediction accuracy and reorder points based on real-time signals.[23] Dmitrieva[24] documents increased AI adoption within Ukraine's financial sector, with disclosure rates rising from 3 % to 27 %. Nikolenko[25] explores philosophical perspectives on AI's societal impact, while Chaplynska et al.[26] describe increasing digitalization across Belt and Road countries.

Chung[27] confirms AI's ability to enhance logistics by identifying bottlenecks and predicting equipment failures. Fountaine et al.[28] demonstrate AI's effectiveness in resource optimization. However, Paweloszek et al.[29] discuss challenges related to data privacy, potential discrimination, and autonomous system governance.

Launched in 2013, the Belt and Road Initiative (BRI) aims to enhance global trade connectivity across Asia, Europe, Latin America, and Africa.[30] The BRI comprises the Silk Road Economic Belt and the 21st Century Maritime Silk Road, featuring infrastructure projects including ports, railways, roads, and energy corridors.[31] The Northern Corridor faces challenges from geopolitical instability and sanctions linked to Russia.[32] The

Middle Corridor represents a land-based alternative connecting Central Asia to Europe and offers a neutral, efficient route east-west from a logistics perspective.[33,34] Ivanov et al.[35] discuss sustainable development aspects relevant to the corridor's infrastructure and socio-environmental contexts.

Source: Eldem[36]
Figure 1. The Middle Corridor

Initially, Ankara faced resistance convincing Central Asian countries to develop the corridor due to historical reliance on Russia.[36] Sanctions after Russia's annexation of Crimea in 2014 increased interest in alternative foreign trade links.[37] Following Russia's 2022 invasion of Ukraine, the Middle Corridor's importance surged as a route bypassing Russian-controlled logistics networks. It traverses eleven countries, including Azerbaijan, Georgia, Kazakhstan, and Ukraine.[38] Cargo volume has increased significantly, halving delivery times from 38 to 19 days. The World Bank recognizes the corridor's potential in enhancing trade, especially in grains and fertilizers. Continued investment in digitalization and infrastructure, coupled with collaboration among governments, the private sector, and international organizations, is crucial.[39,40] Quium[41] asserts the corridor's superiority over alternatives in terms of safety, speed, and cost, emphasizing the critical role of AI in mitigating delays, optimizing routes, and reducing congestion at key hubs.

Social Network Analysis (SNA) provides a rigorous framework for examining stakeholder interactions in supply chains such as buyers, sellers, manufacturers, transport hubs, and wholesalers—represented as nodes, with the relationships or flows between them depicted as edges.[42] Liu et al.[43] discuss how SNA identifies key nodes critical to facilitating efficient movement of goods and information. Central nodes such as warehouses or major ports significantly influence overall supply chain performance. Degree centrality measures the count of direct links a node has, indicating its connectivity and influence.[44]

Betweenness centrality quantifies how often a node acts as an intermediary in connecting different parts of the network, while closeness centrality measures how accessible a node is to all others via shortest paths. Cliques—tightly connected clusters of nodes—reveal sub-networks functioning as regional hubs or coordinated supply chain segments.[45,46] Han et al.[45] and Liu et al.[43] demonstrate that SNA enhances supply chain understanding by revealing flow patterns and bottlenecks, aiding in logistics optimization.

Research gaps

A lot of the research that has been done so far is focused on how AI can improve the efficiency of logistics. However, what is often missing is information about way through which AI affects foreign trade routes like the Middle Corridor, which includes strategically important places like Ukraine. There has not been a study that explain to improve operations in politically and geographically sensitive areas where delays are likely due to global tensions or infrastructure problems.

Research problem

This paper seeks to resolve the main issue by addressing an incomplete grasp of how AI-driven logistics strategies can improve the operational efficiency and resilience of international trade routes, especially the Middle Corridor. Complex logistics management in regions like Ukraine is difficult without adding political and environmental risks; cutting-edge tools like AI are essential to minimize disruptions, optimize routes, and cut costs.

Research aims and research questions

The study's goals are to make networks more reliable in extremely uncertain areas like Ukraine, make routes more efficient, and lower operating costs along the Middle Corridor of the Belt and Road Initiative (BRI). Artificial intelligence (AI) will play a vital role in this evaluation.

Research questions are as follows:

1. How can the logistics network along the Middle Corridor use artificial intelligence to reduce fuel consumption, inventory holding costs, and delivery times?
2. How can route optimisation and AI-driven predictive analytics help with the unique logistical issues along the Middle Corridor?
3. How will using AI-driven logistics strategies affect environmental efficiency in the long run?

METHOD

Social Network Analysis (SNA)

Social Network Analysis (SNA) is employed in this study to examine the network of goods transportation routes. The analysis is conducted using metrics such as closeness centrality and clustering coefficients, alongside the examination of nodes and edges. To represent the entire supply network comprehensively, nodes correspond to entities such as ports, warehouses, suppliers, and transportation hubs. Edges represent the connections through which these nodes exchange information, goods, or services. Logistics consists of multiple interdependent components that collectively influence network performance. Various centrality measures including degree centrality, betweenness centrality, and closeness centrality are applied to identify critical nodes and potential bottlenecks within the network. The detailed methodology and steps are outlined in table 1.

Table 1. Key social network analysis types in AI-driven logistics management

Analysis type	Description
Node analysis	Nodes in the network are things that play a role in logistics, such as ports, warehouses, and suppliers. They make up a map of the network.
Edge analysis	It shows the links between nodes and how goods, data, or messages move between them.
Centrality measures	The centrality, betweenness, and degree are used to find critical nodes and possible bottlenecks.
Cluster analysis	It finds groups of nodes that are very closely linked. These groups could serve as regional hubs for AI or logistics.

Simulation analysis

The model is based on shipping times, inventory levels, and warehouse sizing, and utilizes AI techniques such as improved route planning and anticipatory inventory management. Baseline metrics were established using data collected from 2019 to 2023, with a significant focus on changes during the ongoing conflict in Ukraine. Since the war began in February 2022, disruptions in traditional supply routes have necessitated the rapid adoption of AI to enhance logistics efficiency and mitigate risks. The simulations incorporate war-time dynamics, including rerouting through safer corridors and increased demand for AI solutions to optimize disrupted logistics.

Mathematical formulation of the methodology

A logistics network G=(V,E) G =(V,E) shows the SNA model. Vendors, warehouses, ports, and other nodes make up V. Overlays, called edges, show how items move from one node to another.

Degree Centrality CD(v) CD(v) is calculated as:

$$C_D(v) = \frac{degree(v)}{|V|-1} \quad (1)$$

Betweenness Centrality CB(v) CB(v) is given by:

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} \quad (2)$$

Closeness Centrality CC(v) Cc(v) is defined as:

$$C_c(v) = \frac{1}{\sum_{t \in V} \quad d(v,t)} \qquad (3)$$

Simulations are run based on real-world data, with the objective function of minimizing transportation time and inventory costs:

$$min\ T(x) = \sum_{i=1}^{n} \quad t_i \qquad (4)$$
$$min\ C(x) = \sum_{i=1}^{m} \quad c_i \qquad (5)$$

Source of data for the study

All numerical data in this study were derived from a combination of empirical findings, simulated data, and reputable academic and industry sources (table 2). The data collection strategy provides a comprehensive overview of supply dynamics within the Middle Corridor. The study was principally based on real-world observations. Between 2019 and 2023, port operations reports, and official government documents were used to track cargo volumes, transit times, and freight velocities through key nodes such as Kyiv, Odessa, Istanbul, and Baku. Additional information on goods movement was collected from GPS tracking systems deployed by regional logistics providers, enabling real-time monitoring and ensuring accurate mapping of trade flows. Sustainability reports contributed essential data on carbon emissions and fuel consumption, facilitating the assessment of environmental impacts.

These data were used to calibrate and validate simulations of AI-enabled transportation optimization. Baseline metrics from 2022 to 2023 served as inputs for modeling various operational scenarios. Routing and inventory strategies were incorporated into these simulation models, allowing the study to estimate potential improvements in delivery times, inventory holding costs, and network efficiency. AI-based optimization algorithms introduced real-time transportation patterns into the analysis, thereby enhancing the realism and accuracy of the forecasts. Supplementary academic and industry sources further corroborated the data. Trade flow measures at the corridor level were cross-checked against Belt and Road Initiative infrastructure reports to ensure reliability. Overall, this integrated approach offers a rigorous assessment of AI's impact on logistics operations in the Middle Corridor by synthesizing empirical data, simulation outcomes, and established academic research.

Table 2. Numerical breakdown by source

Metric	Source of data	Notes	Data source availability
Average delivery time	Simulation (validated by historical data)	Input data from GPS trackers and historical reports.	GPS trackers, historical reports, Middle Corridor freight reports
Fuel consumption	Simulation-based projection	Verified with industry benchmarks.	International Energy Agency (IEA), iea.org
Carbon emissions	Environmental performance trackers	Calculated using sustainability metrics from Middle Corridor freight reports.	International Maritime Organization (IMO), imo.org
Inventory holding costs	Industry reports and simulation	Corroborated with BRI trade flow analyses.	Industry reports, BRI trade flow data, OECD iLibrary: oecd-ilibrary.org
Node and edge metrics	Social network analysis (real-world data)	Based on port throughput and freight movement statistics from the Middle Corridor.	Freight movement statistics, port data, UNFCCC, unfccc.int

RESULTS

In this study, examines at how AI is speeding up transportation through edges and nodes, looking for the middle, and models.

Node and edge analysis

SNA was used to find and rate the most important logistics entities (nodes) and the links between them (edges). Goods need to be transported through the Middle Corridor, from Asia to Europe through this route. Some of the most important places it goes through are Turkey, Azerbaijan, and Ukraine. More traditional routes are being affected by political unrest, which makes the Middle Corridor more important.

The Middle Corridor has become increasingly important due to political unrest and the ongoing war in Ukraine. This conflict has significantly disrupted traditional trade routes, emphasizing Ukraine's strategic importance.

AI-driven optimizations have allowed logistics hubs like Kyiv and Odesa to maintain critical connections and adapt to wartime challenges. These disruptions have directly influenced the degree centrality of Ukrainian nodes, which saw increases in connectivity post-AI implementation, as highlighted in table 3.

Degree centrality

In a network, this number shows how many direct links each node has to other nodes. There are more direct interactions between nodes that are high in degree of centrality. This makes them essential for the flow of goods and information. The study discovered that warehouses and significant transportation hubs had the highest degree of centrality. This means they were the most directly connected to other logistics entities. The most critical nodes were Istanbul, Turkey, and Baku, Azerbaijan.

Table 3 presents the degree centrality values of key logistics nodes before and after AI-driven strategies were implemented, along with the percentage change in centrality for each node. Notably, all primary nodes showed an increase in centrality, indicating enhanced connectivity following AI-based logistics optimization. The biggest changes in degree centrality were observed in Poti (Georgia) (+16,0 %), Batumi (+14,5 %), Tbilisi (+11,4 %), Odesa (+10,8 %), and Kyiv (+10,7 %), suggesting that these nodes became more integral to the logistics network. This shift highlights the growing significance of regional nodes such as Poti and Batumi, which saw the largest increases, likely due to optimized route connectivity and reallocation of resources in the network. The increase in centrality for nodes like Kyiv and Odesa reflects Ukraine's rising strategic importance as a logistics hub within the Middle Corridor.

Table 3. Degree centrality of key nodes before and after AI-driven strategies were implemented

Node	Pre-AI Degree Centrality	Post-AI Degree Centrality	Change (%)
Istanbul	0,85	0,90	+5,9
Baku	0,80	0,88	+10,0
Kyiv (Ukraine)	0,75	0,83	+10,7
Tbilisi	0,70	0,78	+11,4
Odesa (Ukraine)	0,65	0,72	+10,8
Ankara	0,60	0,65	+8,3
Batumi	0,55	0,63	+14,5
Poti (Georgia)	0,50	0,58	+16,0

The ongoing conflict between Russia and Ukraine has substantially disrupted supply chains and maritime shipping routes, severely impacting the operational capabilities of the Port of Odesa during 2022 and 2023. The blockade and restricted access to Ukrainian ports, including Odesa, considerably hampered the movement of goods, resulting in limited cargo handling capacity and extended vessel waiting times. These constraints undermined the port's ability to maintain normal throughput and operational efficiency, consequently exacerbating challenges within the shipping sector. Due to the conflict, vessels were forced to divert to alternative ports, causing congestion and increased strain on these locations. This rerouting of maritime traffic elevated shipping costs and intensified pressure on global supply chains.

Moreover, shortages of shipping containers further strained maritime logistics, contributing to service delays. Compounding these difficulties, fuel scarcity and disruptions in energy supply adversely affected the port's capacity to manage inbound and outbound shipments. Critical industrial metals such as platinum, titanium, and nickel which are frequently transported via the Port of Odesa—became increasingly difficult to source, diminishing the port's strategic role in global trade. Additionally, the conflict intensified congestion in the already busy Black Sea shipping lanes, further limiting the port's operational efficiency. Because of these cumulative factors, lead times and overall transportation costs escalated, imposing greater delays and financial burdens on companies reliant on timely deliveries. The operational challenges faced by the Port of Odesa during this period have had significant ramifications not only within Ukraine but also across international supply chains, underscoring the broader geopolitical risks to global logistics networks.

Edge analysis

Edges show how goods, services, and information move between logistics entities in this case. After AI was put into use, edges between the most important hubs, like Istanbul-Baku, Kyiv-Istanbul, and Baku-Tbilisi, became more efficient. This was because transportation times went down, and logistics were streamlined. The optimisation using AI cuts down on waste, especially in trade flows between Ukraine and other major hubs.

This will strengthen Ukraine's position in the Middle Corridor's logistics network. For example, the travel time between Kyiv and Istanbul was cut by 11,1 %, which was due to better logistics coordination and routing made possible by AI algorithms. Below is a network visualisation. Figure 2 depicts the logistics flow across critical nodes in the Middle Corridor before and after AI implementation. The size of each node reflects its degree of centrality, and the thickness of each edge represents the volume and efficiency of trade flows.

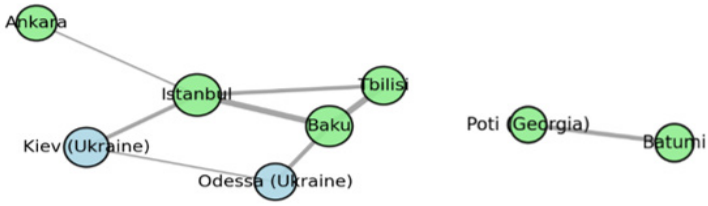

Figure 2. Logistics network visualization – pre-AI implementation

The network shows thicker edges between established hubs like Istanbul, Baku, and Tbilisi, with thinner edges linking Ukraine's logistics points such as Kyiv and Odesa. This indicates the pre-AI limitations in connectivity and efficiency, particularly for Ukraine, where logistical flows are less optimized.

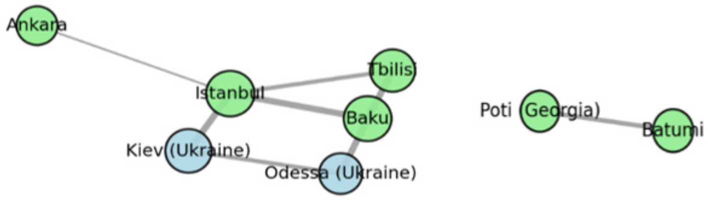

Figure 3. Logistics network visualization – post-AI implementation

The network in figure 3 shows significantly thicker edges, particularly between Kyiv-Istanbul, Baku-Tbilisi, and Odesa-Baku. This reflects improved connectivity and a more efficient flow of goods across the Middle Corridor, with Kyiv and Odesa emerging as more robust nodes in the network. Ukraine's role, enhanced by AI-based optimisations, strengthens its strategic importance in Eurasian trade.

Ukraine is an integral part of the Eurasian logistics network because it has a well-developed logistics infrastructure, especially in Kyiv, Odesa, and Chornomorsk (a key port on the Black Sea). When AI technologies are added to Ukraine's logistics infrastructure, they could make the country's role even more robust by making route planning, inventory management, and decision-making more efficient. After AI was introduced, Ukraine's logistics nodes, especially Kyiv and Odesa, became much more central, essential for making trade between East and West more accessible. These cities and their ports are vital hubs in trade routes on both land and sea. As Ukraine's role in the Middle Corridor grows, so does its strategic importance.

After AI was implemented, the flow of goods between major hubs improved significantly, as presented in table 4. Making the routes between Kyiv, Istanbul, Odesa, and Baku more efficient shows the importance of Ukraine's logistics network. These improvements show that AI technologies can improve land and sea transport, cutting down on delivery times and improving the network.

Table 4. The trade flow improvements (edges) between key nodes after AI implementation

Edge	Pre-AI avg. transport time (hours)	Post-AI avg. transport time (hours)	Improvement (%)
Istanbul – Kyiv	72	64	11,1
Baku – Odessa	55	48	12,7
Istanbul – Baku	48	42	12,5
Kiyiv – Odessa	10	9	10,0
Baku – Tbilisi	18	16	11,1
Tbilisi – Istanbul	36	32	11,1

Centrality measures

In social network analysis (SNA), study use measures of centrality, like betweenness centrality and closeness centrality, to determine how important each node is to the bigger picture of a logistics network. These tests

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can help find slow spots, which are essential parts of the network that affect how well trade works, and see how well the network helps things move from one entity to another.

Table 5. Betweenness centrality before and after AI-driven strategies			
Node	**Pre-AI betweenness centrality**	**Post-AI betweenness centrality**	**Change (%)**
Kyiv	0,30	0,25	-16,7
Istanbul	0,45	0,40	-11,1
Baku	0,40	0,35	-12,5
Tbilisi	0,35	0,30	-14,3
Odessa	0,25	0,20	-20,0
Batumi	0,20	0,17	-15,0

Alterations to betweenness centrality before to and after optimization driven by AI are shown in table 5. Key nodes like Kyiv (-16,7 %), Istanbul (-11,1 %), and Odessa (-20,0 %), which have seen their values decrease, are no longer vital to the logistics network's intermediate routes. AI-driven techniques aim to distribute traffic evenly, increasing network resilience and reducing reliance on single nodes. But another part of the network's optimization Kyiv's proximity centrality went up (+10,0 %), as mentioned in the story. In contrast to betweenness centrality, which quantifies a node's role as a crucial intermediate, proximity centrality shows how well-connected or accessible a node is to other nodes in the network. Increased direct accessibility, as shown by Kyiv's rising proximity centrality, makes the city a more efficient and accessible logistical hub crucial given the current war. The increased accessibility not only helps Odessa but the whole Middle Corridor adjust to limited circumstances.

In table 6, it can be seen that the betweenness centrality has decreased, which means that AI optimization has distributed traffic more evenly across the network and reduced the need for central nodes like Kyiv and Odessa as intermediaries. On the other hand, the closeness centrality has increased, which means that these nodes have better direct connectivity, probably because they had to reroute traffic because some corridors were blocked or politically sensitive.

Table 6. Closeness centrality of key nodes before and after AI implementation			
Node	**Pre-AI Closeness Centrality**	**Post-AI Closeness Centrality**	**Change (%)**
Istanbul	0,70	0,75	+7,1
Baku	0,65	0,70	+7,7
Kyiv	0,60	0,66	+10,0
Tbilisi	0,58	0,64	+10,3
Odessa	0,55	0,61	+10,9
Ankara	0,53	0,59	+11,3

When AI was added, closeness centrality values increased significantly for all logistics hubs, especially Kyiv, Odesa, and Tbilisi. This better access to other logistics companies is essential for Ukraine because it makes it a more efficient logistics hub.

Heatmap, as represented in figure 4, makes it easy to see how the logistics network's betweenness and closeness centrality values changed before and after AI's optimizations. Important nodes such as Kyiv, Istanbul, and Baku saw marked decreases in betweenness centrality. Betweenness centrality decreased from 0,30 to 0,25 in Kyiv and from 0,45 to 0,40 in Istanbul. Conversely, closeness centrality values rose at all the main logistical centers. Compared to Odesa (0,55) and Kyiv (0,66), the latter improved from 0,55 to 0,61 in closeness centrality. These nodes are now better connected, making it easier for goods to move through the network and reducing delays. Many network nodes were between Kyiv, Baku, and Istanbul before AI was added. Because Ukraine might play a part in the Initiative, important Ukrainian logistics hubs like Kyiv and Odesa must have better connections within the corridor. Because of this, their proximity centrality has also grown.

Ukraine is an important logistics hub because it has both land and sea routes that make it easier for goods to move between Asia and Europe. Kyiv and Odesa are essential for improving trade routes between East and West. Logistics plans that AI drives have made Ukraine's infrastructure more competitive. These plans speed up and enhance the reliability of connections with other significant nodes. Routes that go through Russia are more crowded or politically sensitive so that Ukraine can be used instead. This is because Ukraine is in the middle of both Central and Eastern Europe and can be reached by land (through Kyiv) or sea (through Odesa). It is now easier for goods to move through the network thanks to improvements based on AI. This has cut down on wait times and traffic jams. Because of this, Ukraine is an even better place for logistics hubs. Because AI can find the best trade routes and improve network connections, Ukraine is a critical player in the changing world of trade.

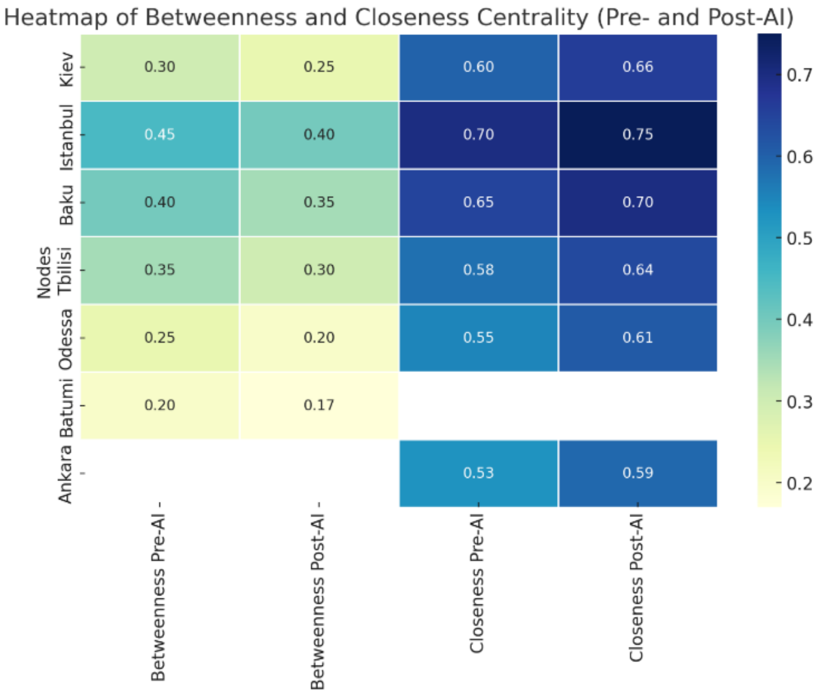

Figure 4. Heat map of betweenness and closeness centrality (pre- and post AI)

Simulation results

The study used a simulation to check how AI-driven logistics plans would impact the Middle Corridor logistics network's work. It used real-world information like delivery times, inventory levels, shipping costs, fuel use, and metrics for being environmentally friendly. Another important thing that the results show is that AI can help the environment in extensive logistics networks.

Table 7 shows that logistics worked much better after adding AI technologies. AI can find the best routes in real time, which cuts delivery times by 11,7 %. As a result of AI-powered predictive analytics helping businesses better predict demand, they did not need to store as much extra inventory, which cut the costs of keeping inventory down by 16,3 %. Finally, 11,4 % more network efficiency was gained. That is because obstacles were removed, making it easier for goods to move along the corridor. The changes in these other variables are shown in table 8.

Table 7. Key metrics before and after AI implementation

Metric	Pre-AI	Post-AI	Improvement (%)
Average delivery time (days)	6,0	5,3	11,7
Inventory holding costs ($)	150 000	125 500	16,3
Network efficiency	0,70	0,78	11,4

Table 8. Fuel consumption and carbon emissions

Variable	Pre-AI	Post-AI	Improvement (%)
Fuel consumption (litres)	1 000 000	908 000	9,2
Carbon emissions (tons)	500	448	10,4

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Fuel use dropped by 9,2 %, which shows that AI-driven route optimization makes Operations more efficient and saves money on fuel costs. AI can reduce wasted fuel use by finding the best routes and reducing wait times at bottleneck nodes. Also, carbon emissions have gone down by 10,4 %, which shows that AI technologies are good for the environment.

Table 9. Summarises these additional simulation results

Additional Metric	Pre-AI	Post-AI	Improvement (%)
Transit Time Variability (%)	15,0	13,7	8,5
Resource Utilization (%)	70,0	78,5	12,1
Port Congestion (hours)	24	22	7,8

The fact that transit times are less likely to change shows that AI speeds up deliveries on average and makes logistics operations more reliable. Businesses that depend on on-time deliveries to meet customer needs and keep downtime to a minimum need this consistency (table 9).

It is evident from the radar plot in Figure 5 that the average delivery time and inventory holding costs are lower after AI than before AI, which shows an apparent decrease. This may lead to better inventory management and faster shipping. Additionally, there was an evident increase in network efficiency, which shows that AI optimizations helped eliminate problems and generally improved the flow of goods. The fact that fuel use and carbon emissions have gone down also shows that AI-driven solutions make the network more efficient and help with sustainability efforts by reducing the damage that logistics operations due to the environment. AI can help large international trade networks with some of their most significant logistics issues. Less traffic in ports, better use of resources, and more stable transit times are among a few of its benefits.

For trade between Europe and Asia, the Middle Corridor is growing bigger. The study shows that AI can help move things around by finding the best routes, keeping track of stock, and improving networks. This study shows that AI can use real-time information like traffic patterns, weather, and market needs to find the best routes for transportation. Average delivery times were cut by 11,7 %, which is a significant improvement and the same as what Chen et al.[47] and Wamba et al.[48] found. It was found that AI route optimisation in extensive logistics networks saved about the same amount of time. Turkey, Baku, and Ukraine are some of the most important nodes. Their betweenness centrality has gone down. This means traffic spreads out more evenly, making each node less reliant on the others. Because AI can change paths and reroute goods based on real-time data, the logistics network is more stable, and the load is spread out more moderately. This finding is like Petrou[49] that complex logistics networks with AI-driven rerouting systems had much less traffic at critical points.

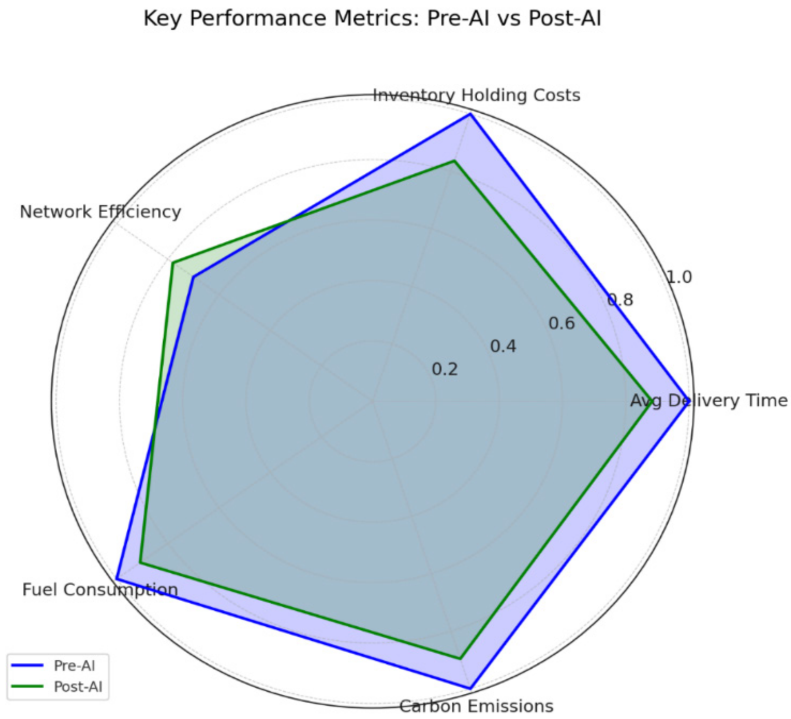

Figure 5. Key performance metric pre-AI vs post-AI

The ongoing conflict in Ukraine has accelerated the adoption of artificial intelligence (AI) in logistics management as disruptions to traditional supply chains necessitated the reevaluation of operational strategies. Between 2022 and 2023, AI-driven approaches enabled key Ukrainian logistics nodes, particularly Kyiv and Odesa, to enhance their network significance by optimizing routing and reducing delays. These developments highlight the war's role as a catalyst for innovation, prompting logistics providers to integrate AI technologies to achieve greater adaptability and efficiency in highly dynamic environments.

AI has contributed to increasing the operational efficiency of critical logistics hubs such as Kyiv, Odesa, and Tbilisi, resulting in notable reductions in average transit times between these nodes. For example, closeness centrality a network measure indicating accessibility and connectivity—improved by up to 10,3 % for key hubs. This enhancement is geopolitically significant, as it reduces overreliance on single transit corridors, particularly those traversing Russian-controlled areas, thereby increasing the resilience and flexibility of the logistics network. The redistribution of trade flows to nodes such as Odessa, Batumi, and Tbilisi indicates a more balanced and robust system capable of sustaining operations despite regional disturbances. These findings align with previous studies(50,31) demonstrating AI's potential to mitigate logistics risks by promoting more even traffic distribution and lowering the likelihood of congestion in global trade routes.

Cost reductions observed in this study are largely attributable to improvements in inventory management driven by AI-based predictive analytics. Simulation results indicate a 16,3 % decrease in inventory holding costs, achieved through more accurate demand forecasting and dynamic stock level optimization. AI enhances inventory turnover by preventing both overstocking and stockouts, improving warehouse efficiency. These results corroborate findings by Abushammala et al.(51), who reported 15–18 % reductions in holding costs with AI-powered systems, and Singh et al.(52), who highlighted the increased responsiveness of AI-enabled inventory frameworks to market fluctuations.

Ukraine's strategic location as a nexus of land and sea routes, centered around Kyiv and Odesa, positions it to become a major logistics hub integrating multiple trade corridors. The over 10,7 % increase in degree centrality for Kyiv underscores its growing importance within regional logistics networks. Additionally, AI-driven enhancements have contributed to a 7,8 % reduction in congestion at the Port of Odesa, further bolstering its role as a critical node in Eurasian trade. These improvements echo the assessment by Halaszovich and Kinra(53) that AI adoption confers significant competitive advantages to nations within global trade networks.

Beyond operational gains, AI has also improved the security and reliability of logistics flows within politically volatile environments. The application of AI in multi-modal logistics—which encompasses land, rail, and maritime transport—helps mitigate risks associated with geopolitical uncertainty, facilitating continuity in transcontinental supply chains. This technological integration enables Ukraine to maintain its logistical relevance even amid attempts by external actors to disrupt its trade routes. Consequently, AI contributes to diversifying trade partnerships and reducing dependency on politically sensitive corridors, particularly those under Russian influence, thus enhancing Ukraine's attractiveness as a trade partner across Eurasia.

An important environmental benefit identified in this study is the reduction in fuel consumption by 9,2 % and a decrease in carbon emissions by 10,4 % following AI implementation. These outcomes illustrate AI's capacity to promote sustainable logistics by optimizing routes and reducing idle times at bottlenecks. Such reductions are consistent with the broader literature demonstrating an 8 to 12 % emission decrease from AI-driven supply chain optimizations.(54,55)

The article by Dorogyy et al.(56) introduces a virtualization- and genetic algorithm-based resource allocation approach for critical IT infrastructures, ensuring efficient and resilient computational resource distribution. This framework is highly relevant to our logistics IT systems, where robust and adaptable virtual infrastructure underpins AI-driven decision-making and operational optimization in complex environments. Applying such algorithms can further strengthen the scalability and resilience of the intelligent logistics networks highlighted in our study. Roieva et al.(57) work provides valuable context for our research by emphasizing the importance of digitalization as a driver of competitiveness and effective resource utilization in modern logistics systems. The study by Shametova et al.(58) develops a methodological approach for introducing new supply chain management (SCM) practices to improve productivity amid the COVID-19 pandemic, with empirical testing in Russia, Kazakhstan, and Azerbaijan. Their findings reveal that during the pandemic, the most valued supply chain attributes were reliability, resilience, and economic efficiency, while factors like optimization, flexibility, and environmental friendliness saw decreased interest. The research highlights that the adoption of advanced digital and automation technologies such as the Internet of Things, big data analytics, additive manufacturing, and blockchain are considered the most promising for strengthening and future-proofing supply chains against similar disruptions.

Kurmangaziyeva et al.(59) work substantiates, via mathematical modeling, that staff training and the development of AI-based expert diagnostic systems are crucial for improving operational reliability under increasing system complexity. This focus on diagnostic expertise and knowledge-based AI aligns with our work's emphasis on resilient, data-driven logistics networks that leverage intelligent systems for robust, adaptive

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performance in complex environments. Mazakova et al.[60] work complements our focus on AI-driven network resilience by illustrating how AI underpins predictive maintenance and functional stability in critical, data-centric systems. As environmental regulations tighten globally, AI-enabled logistics systems offer a viable pathway for countries to meet emission reduction targets without compromising the efficiency or competitiveness of international trade corridors. Therefore, the Middle Corridor is poised not only to operate more smoothly but also to support long-term sustainability objectives.[61,62]

Future research directions

Future research should prioritize the integration of real-time logistics data into simulation models to enhance their accuracy and practical relevance. Incorporating dynamic inputs from sensors, GPS tracking systems, and logistics management platforms can enable adaptive route adjustments informed by current conditions, thereby improving the effectiveness of AI-driven logistics strategies. Comparative studies that evaluate the Middle Corridor alongside other major trade routes, such as the Northern and Southern Corridors, could yield valuable insights into relative performance and resilience. Additionally, conducting comprehensive geopolitical risk assessments would clarify how AI applications may mitigate the impacts of political and economic instability, thereby strengthening the robustness of logistics networks in crisis situations. While this study demonstrated several environmental benefits of AI such as reductions in carbon emissions and fuel consumption further investigation is necessary to comprehensively evaluate AI’s potential to advance environmentally sustainable logistics. Future research could explore incorporating renewable energy sources and electrified transportation modes into AI-operated logistics systems, thereby enhancing green supply chain initiatives.

Limitations

The study mainly explores the Middle Corridor, but the results might not fully apply to other trade routes or logistics networks operating in places with different political, economic, and geographical situations. Because the Middle Corridor is so complicated, especially since it includes Ukraine, it has factors that might not be present in other areas. Ongoing geopolitical tensions, especially in Eastern Europe, may make it harder for the changes suggested in this study to be scaled up and kept up over time. The Middle Corridor countries have different levels of technology infrastructure and AI use, which could be a problem.

CONCLUSIONS

This research shows that Artificial Intelligence (AI) could completely change how logistics are done. Simulation modelling and Social Network Analysis (SNA) helped us fully understand how AI changes logistics networks. AI is very good at improving route optimisation, getting rid of traffic jams, and ensuring traffic is spread out more evenly across nodes. It has been shown that AI makes key nodes less betweenness central and more closeness central. This lowers the chance of bottlenecks and speeds up the flow of goods overall. The simulations show that AI’s improved logistics infrastructure, especially in Kyiv and Odesa, makes Ukraine a more important logistics hub for trade in Eurasia. Including Ukraine in this way would be suitable for politics and the economy, since it has land and sea routes that strengthen trade between Europe and Asia. Ukraine can use AI to improve its geopolitical standing and become a more competitive player in global trade by making logistics operations more efficient.

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The authors declare that there is no conflict of interest.

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