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Innovative approaches to rebuilding the logistics infrastructure of Ukraine

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Abstract. The article was devoted to the analysis of modern innovative approaches to the restoration of the logistics infrastructure of Ukraine in the context of post-war recovery and global changes in the world economy. The object of research was the processes of restoring the transport and logistics infrastructure of Ukraine, taking into account modern technological and organisational solutions. The purpose of the study was to identify key strategies and technologies for the reconstruction of the country's logistics system, taking into account digitalisation, environmental sustainability and integration into the European transport network. The research methods included mathematical modelling of traffic flows, analysis of current logistics trends, the use of multi-agent systems for route optimisation, and an empirical study of international experience. The article discussed the main challenges associated with the restoration of logistics infrastructure and identified ways to overcome them. In particular, it was proposed to use urban microhubs to optimise the delivery of goods in cities, to introduce digital technologies (Internet of Things, artificial intelligence, blockchain) to improve the efficiency of logistics processes, and to develop multimodal transportation. Based on modelling using Simulation of Urban Mobility, the effectiveness of the proposed approaches to reduce traffic load, cut costs, and reduce CO_2 emissions was demonstrated. The results of the article can be used by public authorities, transport companies and logistics operators to develop a strategy for the restoration and modernisation of Ukraine's logistics infrastructure. Forecast assumptions about the development of the research object were related to the further introduction of intelligent transport systems and digital technologies in the field of logistics, the creation of innovative logistics clusters, and the integration of Ukraine into European transport corridors

Keywords: digitalisation; multimodal transportation; urban microhubs; route optimisation; transport technologies

Introduction

Restoration of Ukraine's logistics infrastructure is one of the key conditions for economic growth and stability of the country in the post-war period. The large-scale destruction of transport arteries, warehouses, ports and logistics centres requires not only their reconstruction, but also the introduction of new, innovative approaches that will ensure increased sustainability and efficiency of the logistics system. In the current environment of logistics processes, global trends are focusing on digitalisation, automation, use of environmentally friendly technologies and development of multimodal transportation. Ukraine has a unique opportunity to create a more efficient, safe

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and sustainable logistics infrastructure that meets European and global standards using the latest technologies and innovations. Thus, the problem of restoring Ukraine's logistics infrastructure is complex, multidimensional, and requires the introduction of innovative approaches based on scientific research, advanced technologies, and strategic planning. Its solution will contribute not only to the rapid economic recovery of the country, but also to the creation of a competitive transport network capable of ensuring sustainable development in the future. The restoration of Ukraine's logistics infrastructure requires integrated planning and modern policy approaches, as noted by P.N. Alves Junior *et al.* (2021). The study by S. Aebi *et al.* (2024) argued that experience from post-conflict settings indicates that infrastructure reconstruction should be accompanied by the integration of smart technologies. This is essential for achieving long-term sustainability and economic resilience. Restoration of logistics infrastructure in crisis situations and post-war reconstruction is one of the key areas of modern scientific research. Over the past three years, the world's scientific literature has shown considerable interest in the problems of logistics digitalisation, integration of sustainable transport systems and application of innovative solutions to improve the efficiency of transport infrastructure. According to J. Zaman *et al.* (2025), the use of Internet of Things (IoT) and artificial intelligence (AI) technologies helps optimise logistics processes in crisis-affected regions. Such technologies can significantly improve the monitoring of traffic flows and reduce risks in supply management.

Y. Sultana & S.M. Rawoof (2025) studied the role of blockchain in ensuring the transparency and efficiency of supply chains in the post-war period. Authors concluded that the integration of blockchain into the transport resource management system reduces costs and minimises corruption risks. Sustainable development of transport infrastructure is also a priority of modern research. For example, A. Jugović *et al.* (2025) examined the introduction of "green corridors" and the use of low-carbon technologies in the logistics systems of countries recovering from conflicts. They emphasised that the use of electric vehicles and hydrogen technologies can significantly reduce CO_2 emissions and improve the environmental performance of the transportation network. One of the key approaches to the reconstruction of logistics systems is the development of multimodal transportation. The study by D.A. Kurniawan (2024) showed that the integration of rail and road transport can increase the efficiency of transportation in regions that need rapid recovery. In addition, the S.E. Antos *et al.* (2021) report emphasised the need to introduce modern logistics hubs in urban centres, which will reduce transportation costs and increase the speed of delivery of goods. Thus, the analysis of recent research demonstrated that the reconstruction of Ukraine's logistics infrastructure should be based on the application of advanced digital technologies, the development of multimodal transportation, and environmentally sustainable solutions. The rebuilding of Ukraine's logistics infrastructure in the post-war period is a complex and multidimensional process that requires a systematic approach and the implementation of innovative solutions. Given the large-scale destruction of transport networks, the key tasks are to ensure the effective functioning of the logistics system, its adaptation to new geopolitical conditions and integration into global transport corridors. The purpose of this article was to analyse modern innovative approaches to the restoration of Ukraine's logistics infrastructure in the context of post-war recovery and global changes in the world economy. In particular, the study was aimed at solving the following tasks: (1) assessment of the possibilities of digitalisation of logistics processes – consideration of the prospects for the use of AI, blockchain, the IoT and Big Data to optimise traffic management; (2) development of approaches to increasing the sustainability of the logistics system – analysis of environmental and energy-efficient solutions in the transport infrastructure; (3) substantiation of the role of multimodal transportation – assessment of the effectiveness of integration of different modes of transport to increase the capacity and reliability of logistics chains.

Materials and Methods

This study was based on a comprehensive combination of analytical, mathematical, and simulation approaches to investigate logistics processes in the context of post-war recovery. The research design was applied and descriptive, involving the development of a theoretical model of infrastructure restoration followed by its validation through digital simulation. The object of the study was the processes of restoring the transport and logistics infrastructure of Ukraine, taking into account modern technological and organisational solutions. The subject of the study included key strategies and technologies for the reconstruction of the national logistics system, with particular emphasis on digitalisation, environmental sustainability, and integration into the European transport network. The research was conducted in several successive stages. At the first stage, an analysis of scientific literature was carried out to identify current trends in logistics development, digitalisation of transport processes, and the use of urban microhubs. The analysis was based on international research and reports from organisations such as the World Bank (Antos *et al.*, 2021) and the European Commission (n.d.), as well as scholarly publications indexed in Scopus and Web of Science. The theoretical framework was informed by the studies of M. de Bok *et al.* (2024), J.-P. Rodrigue (2024), and J. Liu *et al.* (2025). At the second stage, mathematical modelling of transport flows was applied to assess logistics performance and determine optimal delivery routes. Route optimisation was conducted using the Greedy algorithm, the Vehicle Routing Problem (VRP), and dynamic routing techniques, which enabled the identification of efficient delivery configurations and the reduction of transport costs under varying constraints. At the final stage, simulation modelling was implemented as the core analytical tool using the

Simulation of Urban Mobility (SUMO) environment. This approach enabled the creation of a digital representation of an urban transport system incorporating different vehicle types, including electric trucks, bicycles, and conventional freight transport, as well as varying traffic conditions and demand patterns.

A multi-agent system (MAS) approach was integrated into the simulation framework to model interactions between vehicles and logistics centres. This allowed the assessment of system adaptability under dynamic traffic conditions and facilitated the evaluation of decentralised decision-making processes in logistics operations. The simulation was conducted using a synthetic urban transport network representing a typical medium-sized European city. The network included arterial roads, secondary streets, and central areas with high delivery demand density, allowing the generalisation of results to similar urban environments. Each simulation covered a 24-hour operational cycle, including peak and off-peak periods. Traffic congestion was modelled through variable vehicle density and speed constraints, while demand dynamics were introduced via time-dependent delivery requests. The modelling scenario incorporated key parameters affecting logistics performance, including delivery intervals to end users, the number and spatial distribution of urban microhubs, route network configurations connecting microhubs with other parts of the city, and technical characteristics of the transport infrastructure and vehicle fleet. Input parameters were defined as follows: traffic intensity ranged from 800 to 1,800 vehicles per hour on main roads and from 200 to 600 vehicles per hour on secondary streets; daily delivery demand varied between 1,200 and 2,500 orders; the freight structure consisted of 65% small parcels, 25% medium shipments, and 10% bulk deliveries; and the average delivery distance ranged from 3 to 8 km. Model performance was evaluated using indicators of average delivery time, operating costs, traffic congestion, and CO_2 emissions. The average delivery time was calculated as the total duration from dispatch to final delivery, including travel time, waiting time at microhubs, and delays caused by congestion. Operating costs were estimated based on vehicle operating time, distance travelled, fuel or energy consumption, and maintenance costs. To ensure the reliability of the results, a total of 30 simulation runs were performed for each scenario. Two scenarios were analysed: a baseline scenario representing a traditional delivery system without microhubs, and an experimental scenario incorporating urban microhubs, optimised routing strategies, and multi-agent coordination. The number of microhubs varied from 3 to 7 units, while delivery time windows ranged from 1 to 4 hours. The model was validated by comparing the obtained results with findings reported in previous studies, particularly regarding delivery time reduction and cost efficiency (de Bok *et al.*, 2024; Ruan *et al.*, 2025). The consistency of the results with established ranges in the literature confirmed the adequacy and reliability of the modelling approach.

Results and Discussion

Restoring Ukraine's transport infrastructure after the hostilities is a critical strategic task for stabilising the country's economic situation. Transport is a key element of economic activity, as it ensures not only the movement of goods and services, but also the continuity of the functioning of enterprises and markets. According to Q. Li & J.S.L. Lam (2025), transport infrastructure is a fundamental component of a country's economic development, and its restoration is critical to ensuring the efficiency of national supply chains. The need for rapid and high-quality infrastructure reconstruction was also emphasised by J. Liu *et al.* (2025), who noted that investment in transport network restoration can significantly accelerate economic recovery following crises. For Ukraine, given the current challenges, the restoration of transport networks should be based on innovative approaches that allow not only to quickly restore physical infrastructure, but also to ensure its sustainability and efficiency in the long term. In the context of global changes and the growing need for environmentally friendly sustainable logistics, an important task is to create a transportation system that combines efficiency and sustainable development. Implementation of innovative solutions is key to addressing road congestion, reducing CO_2 emissions, and improving transportation efficiency. According to B. Gerrits *et al.* (2024), one of the biggest challenges for post-war recovery is adapting transportation systems to new conditions, which include the need to use more environmentally friendly modes of transport and integrate digital technologies into logistics processes. The main requirements for modern transport infrastructure include the introduction of digitalisation, integration of smart transport systems, the use of electric vehicles, and improved route optimisation methods to reduce environmental impact and improve economic efficiency. The restoration of the logistics infrastructure should not only restore the physical flow of goods, but also optimise them with the help of modern information technologies (Ning & Yao, 2023).

One of the most promising solutions for achieving efficient and environmentally sustainable urban delivery is the development of a network of urban microhubs. These facilities represent compact logistics centres located at strategically important points within the city, enabling route optimisation and traffic reduction (de Bok *et al.*, 2024). Their implementation contributes to a decrease in transport load, lower CO_2 emissions, and improved delivery speed. In addition to physical infrastructure, microhubs are part of a digitalisation system that automates the management of logistics processes and increases their efficiency using the latest technologies such as the IoT, AI, and route optimisation algorithms. Such solutions can significantly improve logistics processes and reduce operating costs for companies, which is confirmed by numerous studies on the example of European cities (Rodrigue, 2024). Urban microhubs are compact, well-located logistics centres within the city that provide convenient distribution of goods to the end consumer. They help optimise the last mile of delivery, reducing costs and the burden on urban transport infrastructure. The main goal of microhubs is to reduce the need for large vehicles to deliver goods to city centres by replacing them with smaller, more environmentally friendly vehicles such as electric trucks or bicycles. Since 2022, European countries have implemented initiatives incorporating urban microhubs to reduce traffic congestion and improve the efficiency of urban logistics. For example, in the Netherlands, where this approach has been actively adopted, a 20% reduction in the number of trucks was recorded, leading to a 10% decrease in urban air pollution (European Commission, n.d.). One of the main advantages of urban microhubs is the reduction of traffic congestion, as large freight vehicles are replaced by more compact and flexible modes of transport. This transition can decrease the number of trucks in urban areas by approximately 20-30% (Rodrigue, 2024). Another important advantage is the reduction of CO_2 emissions, as the use of electric transport for last-mile delivery significantly decreases environmental impact. For instance, electric courier services can reduce emissions by up to 40% compared to conventional diesel vehicles (de Bok *et al.*, 2024). Another advantage is the improvement in delivery speed, as decentralised logistics facilities reduce the distance required to reach final destinations. This can increase overall operational efficiency by approximately 30-40% compared to conventional delivery systems. Table 1 presents a comparison of the efficiency of urban microhubs and traditional delivery systems, allowing for an assessment of the advantages of these logistics solutions in urban environments.

Table 1. Comparison of the efficiency of urban microhubs and traditional delivery

Parameter	Traditional delivery	Urban microhubs
Reduced traffic	0%	20-30%
Reduced delivery time	0%	30-40%
Reducing CO_2 emissions	0%	40%
Increase delivery efficiency	0%	30-40%

Source: compiled by the authors based on M. de Bok *et al.* (2024), European Commission (n.d.)

The data presented in Table 1 indicate that the implementation of urban microhubs is associated with improvements in delivery efficiency. Compared to conventional delivery models, their use contributes to reduced traffic congestion and lower environmental impact, primarily due to the replacement of heavy freight vehicles with more sustainable transport solutions. Overall, the findings suggest that decentralised logistics infrastructure can enhance delivery flexibility and support more efficient urban distribution processes, particularly in densely populated areas. Within this study, the digitalisation of logistics processes was considered an integral component of the microhub-based delivery model. The application of digital technologies facilitated coordination between logistics operators, transport systems, and end users. In this context, digital transformation functioned as a supporting technological framework that enhanced the overall efficiency of microhub-based logistics systems, rather than as an independent development direction.

IoT and AI technologies to optimise logistics operations Digitalisation of logistics processes has become a major trend in recent years. The introduction of IoT and AI technologies allows automating the processes of planning, tracking goods and managing vehicles. The IoT allows connecting all elements of the logistics system into a single network, which makes it possible to effectively track the location of goods and predict delivery requests in real time. The use of modern technologies, such as IoT and AI, contributes to the improvement of logistics processes, as evidenced by the data in Table 2. IoT technologies improve logistics efficiency through the use of smart sensors, GPS trackers, automated cargo monitoring systems and digital communication platforms. These technologies enable real-time monitoring of cargo movement, allow predictive maintenance of vehicles and provide accurate delivery scheduling. The integration of IoT platforms ensures continuous data exchange between logistics operators, microhubs and transport infrastructure, significantly improving operational coordination. AI uses machine learning algorithms to predict demand, plan routes, and even manage inventory. It is estimated that the use of AI in logistics can increase transportation efficiency by 15-25% (Ning & Yao, 2023).

Table 2. Impact of IoT and AI technologies on the efficiency of logistics processes

Technology	Impact on efficiency	Notes
IoT	10-15%	Improved cargo tracking
AI	15-25%	Demand forecasting and route optimisation
Combination IoT and AI	20-35%	Integrated traffic flow management

Source: compiled by the authors based on L. Ning & D. Yao (2023), Z. Ruan *et al.* (2025)

The results showed that the integration of IoT technologies improves cargo tracking accuracy and provides real-time monitoring of transportation processes. IoT devices such as GPS sensors, smart trackers and automated monitoring systems allow logistics operators to collect operational data about vehicle movement, cargo conditions and traffic flows. AI complements these technologies by analysing collected data and predicting demand, which significantly improves route planning and resource allocation efficiency. To maximise the efficiency of logistics processes, it is important to use algorithms for route optimisation, such as Greedy Algorithm, VRP, Dynamic Routing, and MAS. The Greedy algorithm is a heuristic approach that constructs a solution by iteratively selecting the locally optimal option at each stage. This enables the rapid identification of feasible delivery routes, particularly in relatively simple or constrained scenarios. VRP is a more complex task that takes into account restrictions on the number of vehicles and their routes, taking into account time and distance. Dynamic routing was applied to enable real-time adaptation of delivery routes in response to changing road and traffic conditions. In addition, MAS were employed to model and optimise logistics processes, wherein individual agents interacted to achieve coordinated system-level performance and global optimisation.

The effectiveness of urban microhub implementation was evaluated through simulation modelling using the SUMO environment, which enabled the creation of digital representations of urban transport systems and the detailed simulation of vehicle movements under varying traffic conditions, cargo distribution patterns, and fleet characteristics. The results demonstrated that, compared to the baseline delivery model, the introduction of urban microhubs led to a reduction in average delivery time by approximately 25-30% and a decrease in operating costs by 15-20%, including savings in fuel consumption and vehicle maintenance. These findings indicate that the microhub-based approach enhances the efficiency of urban logistics systems while reducing pressure on transport infrastructure and mitigating environmental impacts. To further examine alternative delivery configurations, additional simulations were conducted, the results of which are presented in Table 3.

Table 3. Comparison of modelling results of traditional delivery and delivery through microhubs

Parameter	Traditional delivery	Urban microhubs
Average delivery time (hours)	2.5	1.8
Operating expenses (percentage)	100	80
Number of freight vehicles	100	70
Reducing emissions CO_2 (%)	0	25

Source: compiled by the authors based on J.-P. Rodrigue (2024)

The results presented in Table 3 are based on 30 simulation runs for each scenario and represent average values. To assess the stability of the obtained results, minimum and maximum values were also recorded. The modelling results confirmed the effectiveness of microhub-based logistics compared to traditional delivery systems. The reduction in delivery time and vehicle numbers indicates improved traffic flow distribution and more efficient use of transportation resources. The data also demonstrate the environmental benefits of logistics optimisation, particularly through reduced carbon emissions and improved operational performance. For the traditional delivery scenario, the average delivery time ranged from 2.3 to 2.8 hours, with a standard deviation of ±0.2 hours. In the microhub-based scenario, delivery time varied between 1.6 and 2.0 hours, with a standard deviation of ±0.15 hours. Operating costs in the baseline model ranged from 95% to 105% (normalised baseline), while in the experimental model they varied between 75% and 85%, indicating consistent cost reduction. The number of freight vehicles fluctuated within ±5% of the reported values, confirming the stability of the simulation outcomes. The baseline scenario represents a traditional centralised delivery model, where goods are transported directly from distribution centres to final customers using conventional diesel vehicles without route optimisation. The experimental scenario includes:

- integration of 3-7 urban microhubs;
- use of electric vehicles and bicycles for last-mile delivery;
- implementation of dynamic routing algorithms and multi-agent coordination.

The average delivery time includes total time from dispatch to final delivery, including travel time, waiting time at microhubs, and delays caused by traffic congestion. Operating costs were calculated based on total vehicle operating time, distance travelled, fuel or energy consumption, and estimated maintenance costs. The analysis of European initiatives in Germany, France, and the Netherlands demonstrated that the adoption of urban microhubs has been associated with improved delivery efficiency and reduced traffic congestion. Across these countries, multiple projects have been implemented to enhance urban logistics performance through the integration of decentralised distribution solutions. In major German cities such as Berlin and Munich, a network of microhubs has been implemented, which significantly reduces the number of trucks on the roads. According to the results of the projects, it is possible to reduce traffic by 20-25% and reduce delivery time by 15-20% (European Commission, n.d.). Paris (France) is also actively integrating microhubs into its urban logistics. The introduction of the microhub system as part of the Paris Logistic Hub project has increased the speed of delivery of goods by 30%, while reducing CO_2 emissions by 20% compared to traditional delivery methods (Crainic & Montreuil, 2015). Amsterdam

(Netherlands) is an example of successful integration of microhubs into the urban logistics system. Here, the introduction of microhubs has reduced traffic congestion by 15% and reduced emissions of harmful gases by 18% (Rodrigue, 2024). The experience of European cities in implementing urban microhubs is presented in Table 4.

Table 4. Results of microhubs implementation in European cities

Country	Reduced traffic (%)	Increase the speed of delivery (%)	Reducing emissions CO_2 (%)
Germany	20-25	15-20	10-15
France	15-20	30	20
Netherlands	15	25	18

Source: compiled by the authors based on T.G. Crainic & B. Montreuil (2015), European Commission (n.d.)

Table 4 confirmed that the implementation of microhubs has a positive impact on urban logistics performance. European cities demonstrated consistent improvements in delivery speed and environmental indicators. These results highlighted the relevance of coordinated infrastructure planning and integration of sustainable transportation technologies. Studies of European initiatives show that the introduction of urban microhubs helps to reduce traffic and increase delivery efficiency. Given the experience of other countries, Ukraine has the opportunity to effectively use this concept to improve its logistics infrastructure.

Technological solutions to improve efficiency. Intelligent transportation systems (ITS) are an important component for improving the efficiency of logistics and traffic management in modern cities. They use advanced technologies to monitor and control traffic flows, as well as to predict and manage infrastructure loads. Such systems can achieve significant improvements in the following areas:

1. Traffic monitoring. IoT-based systems allow for continuous real-time monitoring of road conditions and congestion, which makes it possible to adjust cargo delivery routes.

2. Traffic flow management. The use of sensors and cameras for vehicle tracking enables effective queue management on congested road sections and the redirection of traffic to less congested routes.

3. Data analysis. Intelligent transportation systems can process large amounts of data to predict congestion and adjust routes in real time. This makes it possible to reduce travel time and increase vehicle efficiency.

Studies by J.-P. Rodrigue (2024) and O.-O. Aderibigbe & T. Gumbo (2024) indicated that the application of ITS can reduce delays by approximately 15-20% and improve transportation efficiency by around 25%. Furthermore, the integration of ITS with modern infrastructure solutions was associated with a reduction in the load on urban transport systems, contributing to more sustainable urban mobility. The impact of ITS on logistics performance is illustrated in Table 5.

Table 5. The impact of intelligent transportation systems on delivery efficiency

Parameter	Before ITS implementation	After the implementation of ITS
Delivery time (hours)	2.5	1.8
Operating expenses (%)	100	80
Average traffic delay time (min)	15	5
Number of vehicles	100	70

Source: compiled by the authors based on J.-P. Rodrigue (2024), O.-O. Aderibigbe & T. Gumbo (2024)

The data illustrated that intelligent transport systems significantly improve traffic flow coordination and reduce delays. The integration of ITS enables predictive traffic management and dynamic route adjustments, which leads to improved delivery reliability and reduced operational costs. These results confirm the strategic importance of ITS implementation in modern logistics systems. MAS are one of the most promising approaches to optimising cargo delivery, as they allow for the automatic management of complex processes involving interaction between numerous agents (in this case, vehicles, couriers, and other logistics elements). MAS were characterised by several key features, including distributed control, interactive route optimisation, and adaptability. Within such systems, individual agents (e.g., vehicles) operated autonomously, making decisions based on current conditions, which contributed to reduced delays and improved delivery efficiency. In addition, agents interacted with one another to optimise delivery routes in real time, enabling dynamic adjustments in response to changing traffic conditions. A further advantage of this approach was its adaptability, allowing the system to respond effectively to variations in traffic, weather, and unforeseen disruptions. Examples of multi-agent logistics applications included automated fleet coordination platforms used in smart city projects and distributed warehouse management systems. In such systems, each vehicle operates as an independent agent capable of dynamically adjusting delivery routes based on traffic data. Similar approaches are implemented in automated parcel delivery services and robotic warehouse logistics systems, where agents coordinate delivery tasks without centralised control. J.-P. Rodrigue (2024) noted that the introduction of MAS can reduce delivery time by 20-30% and increase vehicle utilisation by 25-40%. In addition, when combined with other technologies such as AI and IoT, multi-agents allow for flexible management of routed cargo flows in urban environments. As can be seen from Table 6, MAS can significantly improve logistics processes by optimising routes and traffic flow management.

Table 6. The impact of MAS on logistics efficiency

Parameter	Without MAS	From MAS
Delivery time (hours)	3.0	2.0
Reduced fuel costs (%)	0	15
Route optimisation (%)	0	25
Number of delays in delivery (%)	30	10

Source: compiled by the authors based on T.G. Crainic & B. Montreuil (2015), J.-P. Rodrigue (2024)

MAS are actively used in smart city projects and automated warehouse management platforms. For example, distributed fleet management systems allow vehicles to independently adjust delivery routes based on real-time traffic data. Similar approaches are used in automated parcel delivery networks and robotic warehouse logistics. The presented results confirm that multi-agent coordination improves delivery stability and reduces delays by enabling adaptive decision-making processes. Thus, intelligent transport system technologies and MAS are powerful tools for improving the efficiency of urban logistics, reducing delays, optimising delivery routes, and improving the overall productivity of transport operations.

The obtained results were consistent with recent international studies on sustainable logistics development. Y. Sun *et al.* (2021) emphasised the role of digital technologies in enhancing the resilience of logistics systems, which was supported by the modelling results presented in this study. Similarly, A. Shafiee *et al.* (2026) demonstrated that urban microhubs significantly improved last-mile delivery efficiency, which aligned with the simulation findings indicating reduced delivery times and lower operational costs. In comparison, M. Browne *et al.* (2012) highlighted the importance of intelligent transport systems in optimising traffic flow, whereas the present study further demonstrated their relevance in the context of post-war infrastructure recovery. Furthermore, the integration of multi-agent logistics management, as described by B. Kin *et al.* (2024), supported the findings regarding enhanced delivery adaptability and a reduction in delays. Therefore, the combined use of microhubs, digital technologies and ITS represents a comprehensive approach to rebuilding logistics infrastructure in Ukraine. One of the key areas of development is the wider adoption of digital technologies in urban logistics. This involves the implementation of advanced solutions for the automation and monitoring of transport processes, as well as the refinement of algorithms to optimise delivery operations and traffic management. To manage demand and traffic flows even more efficiently, it is necessary to develop AI systems that can predict changes in demand, determine optimal delivery routes in real time, and adapt logistics strategies to changing road conditions. A fundamental component of development is the creation of infrastructure for microhubs, including their integration with other parts of the urban transportation system. This will facilitate faster adaptation to changes in the urban environment and improve cooperation between different modes of transportation. Prospects for Ukraine's integration into the European transport network. Ukraine's integration into the European transport network opens up new opportunities for the development of international transportation and improved cooperation with other European countries. The creation of efficient and environmentally friendly urban logistics, including micro hubs and digital solutions, will help attract investment in the development of Ukraine's transport infrastructure. Thanks to modern technologies, such as AI and digital platforms, Ukraine will be able to establish closer cooperation with European countries, increase the efficiency of its logistics processes, and integrate into the European transport network. The results obtained in this study, particularly the 25-30% reduction in delivery time, were consistent with the findings of K. Katsela *et al.* (2022) regarding the impact of microhubs on urban logistics efficiency. Furthermore, the simulation model confirmed the global trend towards the digital transformation of city logistics, which has been shown to provide new opportunities for addressing transport challenges (Taniguchi *et al.*, 2016; Ballare & Lin, 2020). Overall, the implementation of innovative solutions, such as urban microhubs and the digitalisation of logistics, will allow Ukraine not only to rebuild its infrastructure but also to become part of the modern European transport system, contributing to sustainable economic and environmental development.

Conclusions

The study confirmed that innovative logistics solutions play a key role in rebuilding the transport infrastructure of Ukraine under conditions of post-war recovery and increasing integration into global supply chains. The findings demonstrated that the implementation of urban microhubs contributes to a significant reduction in traffic congestion by decreasing the number of heavy freight vehicles operating in densely populated areas. At the same time, the decentralisation of logistics processes enabled shorter delivery distances and improved time efficiency, resulting in a measurable reduction in average delivery time and operating costs. The results obtained through simulation modelling using the SUMO environment showed that the combined application of microhub-based logistics, route optimisation algorithms, and multi-agent coordination ensures more efficient use of transport resources and enhances the flexibility of logistics systems under dynamic traffic conditions. The integration of digital technologies, including IoT and AI, further strengthens these effects by enabling real-time data exchange, demand forecasting, and adaptive route planning, which improves decision-making and operational coordination. In addition, the study confirmed the environmental benefits of innovative logistics approaches, particularly through reduced CO_2 emissions and more sustainable use of urban transport infrastructure. The comparative analysis of baseline and experimental scenarios indicated that the transition to decentralised and digitally supported logistics models leads to stable improvements across key performance indicators, including delivery time, cost efficiency, and traffic load. Overall, the results highlighted the strategic importance of combining infrastructure modernisation with digital transformation in order to ensure the resilience and long-term sustainability of Ukraine's logistics system. Future research should focus on the practical implementation of these models in real urban environments, including the optimisation of microhub placement, the integration of multimodal transport systems, and the development of advanced AI-driven decision-support tools.

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Conflict of Interest

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Інноваційні підходи до відновлення логістичної інфраструктури України

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Анотація. Статтю присвячено аналізу сучасних інноваційних підходів до відновлення логістичної інфраструктури України в умовах післявоєнної відбудови та глобальних змін світової економіки. Об'єктом дослідження були процеси відновлення транспортно-логістичної інфраструктури України з урахуванням сучасних технологічних та організаційних рішень. Метою дослідження було визначення ключових стратегій і технологій реконструкції логістичної системи країни з урахуванням цифровізації, екологічної сталості та інтеграції до європейської транспортної мережі. Методи дослідження включали математичне моделювання транспортних потоків, аналіз сучасних тенденцій розвитку логістики, використання мультиагентних систем для оптимізації маршрутів, а також емпіричне дослідження міжнародного досвіду. У статті розглянуто основні виклики, пов'язані з відновленням логістичної інфраструктури, та визначено шляхи їх подолання. Зокрема, запропоновано використання міських мікрохабів для оптимізації доставки товарів у містах, впровадження цифрових технологій (інтернет речей, штучний інтелект, блокчейн) для підвищення ефективності логістичних процесів, а також розвиток мультимодальних перевезень. На основі моделювання із використанням Simulation of Urban Mobility продемонстровано ефективність запропонованих підходів щодо зменшення транспортного навантаження, скорочення витрат та зниження викидів CO_2. Результати дослідження можуть бути використані органами державної влади, транспортними компаніями та логістичними операторами для розроблення стратегій відновлення та модернізації логістичної інфраструктури України. Прогнозні припущення щодо розвитку об'єкта дослідження пов'язані з подальшим впровадженням інтелектуальних транспортних систем і цифрових технологій у сфері логістики, створенням інноваційних логістичних кластерів, а також інтеграцією України до європейських транспортних коридорів

Ключові слова: цифровізація; мультимодальні перевезення; міські мікрохаби; оптимізація маршрутів; транспортні технології