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Development of existing and new multimodal logistics schemes as steady trend for Ukraine's transport system

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Abstract. The current transformation of international transport corridors, the blocking of sea routes and the redirection of Ukraine's logistics flows necessitate the development of efficient multimodal transport systems and integration into the European logistics space. The aim of article was to study the current trends in the development of Ukraine's transport system, analyse the functioning of multimodal logistics schemes, and identify the prospects for their modernisation in the context of European integration and military challenges. This study involved the use of methods such as system analysis, comparative analysis, statistical evaluation, and the synthesis of scientific sources, analytical reports, and statistical data from international organisations. It has been established that after 2022, Ukraine's transport system underwent a significant transformation linked to changes in the main directions of freight flows and the formation of new multimodal routes through European Union countries. The experience of European countries in optimising the interaction of different modes of transport and stimulating the environmentally safe railway segment has been examined. The analysis revealed the growing importance of dry ports, border logistics hubs and the Danube transport cluster in maintaining the continuity of international supply chains. It has been established that the integration of multimodal schemes with digital logistics management technologies, freight flow monitoring systems and route optimisation tools helps to enhance the resilience of the transport system, reduce logistics costs and minimise risks. It has also been shown that the development of multimodal infrastructure and the harmonisation of Ukraine's transport system with TEN-T standards is a prerequisite for strengthening the country's transit potential and its integration into the European economic area. The practical significance of the results obtained stems from the possibility of applying them in the formation of state transport policy, the modernisation of logistics infrastructure and the optimisation of multimodal transport in Ukraine

Keywords: supply chains; multimodal technologies; transport services; economic partners; freight transportation

Introduction

The effective functioning of the transport system forms the basis of economic stability, the maintenance of foreign trade links and the country's international competitiveness. Due to global geopolitical changes, large-scale infrastructure damage and the forced closure of traditional sea routes, there is an urgent need for a radical restructuring of logistics chains based on multimodality, which makes it possible to minimise financial costs, reduce delivery times and optimise the use of technical resources. Investigation of the possibilities for developing such systems and establishing new land corridors is vitally important for integrating the national network into the Trans-European Transport Network (TEN-T) and enhancing the resilience of the economic system. In accordance with Ukraine's National Transport Strategy until 2030 (Resolution of the Cabinet of Ministers of Ukraine No. 1550-2024-p, 2024), one of the priority areas for the development of the transport sector is the modernisation of multimodal infrastructure and the expansion of integration into the European transport area.

The issues of organising, modelling and improving the efficiency of combined freight transportation under extreme conditions are the focus of many researchers. In particular, the specifics of optimising and restructuring transport routes were investigated by I. Taran *et al.* (2023), who, in their work, established the mathematical dependence of optimisation criteria on the total volume of freight deliveries and proposed an algorithm for synchronising the discrete stages of the multimodal process. The authors have proven that splitting large consignments into separate parts allows for flexible adjustment of carriers'

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variable and fixed costs. Models of integrated planning and the selection of logistics providers were examined by S. Onyshchenko *et al.* (2024). The researchers developed a comprehensive economic-mathematical model aimed at improving operational efficiency and minimising costs by coordinating the schedules of motor, railway and sea transport, taking into account specific regional constraints. I. Derpich *et al.* (2024) analysed the environmental aspects of transport systems and the potential for reducing carbon dioxide emissions. The scientists proposed a strategic approach to the centralised concentration of freight flows and mathematically demonstrated that, under conditions of high transit density, the use of a significant number of intermediate logistics hubs is economically and environmentally inefficient.

The specific features of logistics management in emergency situations and under conditions of direct infrastructure threats are examined in the study by V. Samsonkin *et al.* (2022). The authors developed a digital information and organisational system for security management at the level of large transport enterprises, demonstrating the high effectiveness of simplified route calculation methods during military operations in Ukraine. A.S. Shuaibu *et al.* (2025) examined the problems of cargo delivery within the "last mile" concept as one of the most costly elements of the supply chain. The researchers demonstrated the potential of applying artificial intelligence technologies for dynamic routing and justified the advantages of using hybrid networks that combine unmanned aerial vehicles with traditional vehicles in an urbanised environment. N. Kalicheva *et al.* (2022) examined the processes involved in the development of a network of logistics hubs at the regional and national levels. The researchers identified the key risks associated with the creation of multimodal centres and noted that infrastructure instability and the low quality of ancillary services remain the main obstacles to attracting investment in Ukraine. D.V. Lomotko & H.O. Prymachenko (2023) analysed the importance of the railway sector and its interaction with other modes of transport in the context of the transformation of the geopolitical landscape. The author emphasised the insufficient level of research on economic security issues in the transport sector and argued that it is multimodal technologies which allow the strengths of each means of transport to be maximised at specific stages of the logistics chain. N. Trushkina (2022) examined the challenges of international partnerships and the diversification of freight logistics routes during military conflicts. The author justified the importance of strengthening cross-border cooperation with European Union countries, expanding the use of Danube port facilities, and establishing joint logistics enterprises to ensure the uninterrupted export of agricultural products.

However, despite the existence of a significant body of studies, the mechanisms for adapting Ukraine's logistics infrastructure to rapid changes in transit conditions and integration with specific hubs in Central and Western Europe require further analysis. The purpose of this article was to examine current transformational trends in Ukraine's transport system, to assess the effectiveness of existing multimodal schemes, and to identify strategic priorities for their modernisation.

Literature Review

The organisation, management, and improvement of multimodal freight transport services using effective logistics tools are the subject of intensive scientific research. Current approaches for organising multimodal freight delivery based on the agile approach were proposed in the work by V. Berestenko & S. Onyshchenko (2024). The authors study digital mechanisms for coordinating multimodal transport and the issue of reconciling the interests of participants in the logistics process. The main scientific contribution of the work is the introduction and justification of the concept of the "compromise zone." The authors prove that this "compromise zone" should become a central tool in agile planning cycles. It clearly demonstrates how a change in one customer requirement (e.g., a shorter lead time) affects other parameters (cost, reliability), offering the operator and the customer a set of new alternatives for balancing interests.

The issue of developing Ukraine's transport and logistics infrastructure in the context of European integration and global challenges is highlighted in N. Tyukhtenko (2024). The author systematises the main components of transport and logistics infrastructure and emphasises the need to adapt it to European standards and the principles of sustainable development. The author examines the theoretical foundations of the concept in detail, systematising it into four key components: technical, infrastructural, institutional, and organisational-economic. The article discusses the critical importance of a functioning integrated transport and logistics system and its structural elements – transport and logistics centres. On the basis of global experience of developed countries, the effectiveness of such centres is demonstrated, and their essence, main development goals, and prerequisites for successful implementation in Ukraine are explored. Taking into account Ukraine's unprecedented infrastructure losses due to full-scale Russian aggression, the article outlines priority areas for the reconstruction and modernisation of the branch. These areas are based on the adaptation of advanced European and global experience.

The study by O.V. Svychynska & A.V. Reznyk (2025) analysed the transformation of Ukraine's logistics system amid a full-scale invasion. The authors note a sharp decline in freight volumes in 2022, followed by a gradual recovery during 2023-2024 due to the optimisation of rail transport, the implementation of multimodal logistics schemes, the revitalisation of the Danube transport corridor, and the resumption of international container traffic. At the same time, the study substantiates the feasibility of digitisation the industry (implementing modern management systems). Special attention is given to the socio-environmental challenges of wartime. In particular, the author highlights ways to address labour shortages through retraining programmes for women and the integration of artificial intelligence to automate heavy physical labour. The environmental dimension of the study explores the potential of "green logistics" and the decarbonisation of operations as key drivers of sustainable industrial development. According to the authors' conclusions, the implementation of these priorities will ensure the transition of the domestic logistics market from survival tactics to systematic modernisation and integration into global supply chains.

In her work, V. Puzikova (2024) examined the specific nature of the transformation and the prospects for the recovery of Ukraine's logistics system under martial law. The author emphasises the dual nature of the country's geopolitical position: its status as a logistics hub and high transit index (which, according to 2018 estimates, surpassed those of its closest European neighbours) are combined with the risks of being located in a buffer zone. It has been emphasised that the destruction of industrial and transport infrastructure as a result of Russia's full-scale aggression has necessitated a shift in traditional supply chains, where railways and seaports historically accounted for up to 75% of foreign trade. At the same time, the large-scale destruction has been seen as a determinant for the radical modernisation of the economy through the development of next-generation infrastructure. The key vectors for Ukraine's integration into the global space have been identified as the reform of the transport sector based on multimodality, the optimisation of domestic routes, and the digitalisation of customs regulation. In the paper by A. Karam *et al.* (2023), a theoretical and methodological analysis of the barriers to the development of multimodal freight transport was conducted, and strategies for overcoming them were identified. Based on a meta-synthesis of 104 scientific papers, the authors identified 31 specific barriers hindering the shift of freight flows from road transport to more environmentally friendly alternatives (railway and inland waterways). The article focuses on justifying risk mitigation tools, particularly through digitalisation, the development of synchro-modality, the optimisation of business models, and the strengthening of integration between the government and private sectors.

The research by A. Orozonova *et al.* (2022) analysed the specifics and prospects of integrating smart technologies into the organisation of multimodal freight transportation. The authors argue that traditional methods of logistics analysis are insufficient and propose a new conceptual model of market functioning based on the activities of a smart logistics operator (provider-integrator). The authors developed a unified framework for the thinking and operational context of such an integrator, as well as classified the types of smart technologies implemented by it. Particular attention was paid to the operational characteristics of niche logistics markets – the delivery of special categories of cargo within the submarkets of temperature-sensitive (refrigerated) products, fresh goods, and pharmaceuticals, which require enhanced technological control to ensure compliance with safety and reliability parameters of supply chains. S. Okyere *et al.* (2022) investigated the issue of optimising multimodal transport and logistics systems using genetic algorithms to improve transport efficiency and ensure the sustainable development of the transport sector. The authors emphasise the need to integrate various modes of transport into a single logistics system to minimise costs, reduce delivery times, and lessen the negative environmental impact of transport activities. A model for optimising multimodal transportation is proposed, based on the application of a genetic algorithm to select the most efficient cargo delivery routes. The study takes into account economic, environmental, and time-related transportation parameters, enabling a comprehensive approach to managing logistics processes. The authors claim that the use of intelligent optimisation algorithms contributes to increasing the sustainability of the transport system, improving coordination between modes of transport, and reducing logistics costs.

In a scientific review, D. Kurniawan (2024) summarised theoretical and practical approaches to improve the efficiency and viability of integrated logistics networks through multimodal transportation. Based on an analysis of a corpus of leading publications from 2010 to 2024, the author identifies five strategic dimensions of multimodal systems: economic efficiency, resilience to crises, environmental sustainability, the level of digital integration, and network design architecture. The study demonstrates that the use of synchromodality concepts, Internet of Things technologies, and real-time analytics enables the minimisation of operational costs, the flexible adaptation of logistics chains to large-scale geopolitical or economic crises, and the reduction of the carbon footprint. At the same time, the author states that there are barriers to the large-scale implementation of such solutions, in particular, infrastructure disparities between regions of the world and the fragmentation of regulatory frameworks. The study concludes by justifying the need for institutional reforms and the implementation of adaptive logistics models based on artificial intelligence.

O. Strelko *et al.* (2022) investigated the theoretical foundations for the development of multimodal transport and logistics technologies in the context of integrating Ukraine's transport system into the TEN-T. The research focuses on the formation of modern multimodal infrastructure, the development of logistics centres, and ensuring effective coordination among different modes of transport. The authors argue that harmonising national logistics routes with European standards requires rethinking the coordination of different modes of transport and developing compatible cross-border infrastructure. Special attention was paid to the regulatory and technical compatibility (interoperability) of logistics systems, which is critically important for the seamless integration of domestic operators into European supply chains and the realisation of the country's transit potential. The authors also emphasise the importance of developing railway transport as a key element of the multimodal transport system to the European Union.

The article by K. Cherednichenko *et al.* (2023) is aimed at developing a scientific and methodological approach for assessing the operational safety of multimodal transport systems. The authors critically analyse existing risk management models and identify their key shortcomings, including the problem of local optima, the difficulties of unifying assessments for different modes of transport, and the limitations of safety management in situations where the operator is not the direct owner of the infrastructure. The scientific novelty of the work lies in the development of a mathematical model based on system reliability theory, risk concepts, and critical failures. The proposed tools allow for the consideration of both the objective conditions for the formation and development of a logistics network and the subjective factors involved in ensuring the protection of its facilities. The practical significance of the research is confirmed by the testing of the model on an existing multimodal route, which demonstrates its applicability both for monitoring the current level of security and as a baseline criterion during the design of optimal logistics chains. The authors proposed a methodological approach to security assessment using the example of multimodal transport, which takes into account the shortcomings of existing studies. The practical application of the developed model was demonstrated on an existing multimodal transport system.

The study by J. Gupta *et al.* (2024) highlights the strategic role of multimodal logistics parks in stimulating economic development and optimising a country's macro-logistics costs. Using the example of a large-scale infrastructure project in a multimodal logistics park, the authors demonstrate an approach to the planning and construction of major transportation hubs. Significant attention was paid to the methodological aspects of design, covering the calculation of infrastructure capacities, the implementation of flexible financial mechanisms (in particular, public-private partnerships), as well as compliance with strict environmental standards to ensure the region's environmental safety. The authors claim that the creation of such hubs not only increases the speed and transparency of cargo delivery but also serves as a driver for the development of intelligent transportation systems. S. Fazi & J.C. Fransoo (2025) focused on the study of freight mobility in their work. They proposed and theoretically substantiated the concept of "Freight Mobility as a Service" as a tool for scaling up synchro-modal transport. The authors argue that the concept of multimodality didn't gain widespread practical application due to the critical heterogeneity and fragmentation of transport offerings, as well as the specific nature of freight requests. Unlike most existing digital platforms, which operate on an "on-demand" basis, the FMaaS (Freight Mobility as a Service) model integrates regular schedules of linear services (rail, barge, and coastal shipping) into flexible and transparent delivery chains. Despite the commercial, legal, and psychological barriers to the implementation of FMaaS, the authors argue that this approach dramatically increases network capacity utilisation and is key to the sustainable and environmentally friendly development of global logistics.

Materials and Methods

The study on the development of multimodal logistics schemes in Ukraine was based on a comprehensive approach to the analysis of transport processes, international logistics routes, and the integration of Ukraine's transport system into the European transport area. The methodological basis of the work consisted of general scientific and specialised research methods, the application of which enabled a systematic analysis of current trends in the development of multimodal transport and the identification of prospects for modernising the transport and logistics infrastructure. The sequence of the research process comprised three interrelated stages: the collection and systematisation of source data, statistical and analytical processing of information, and the formulation of practical recommendations for the modernisation of transport corridors. The study applied a systematic analysis method, which allowed for the examination of Ukraine's transport system as a complex integrated mechanism of interaction between rail, road, maritime, and river transport. Using this method, the study identified the characteristics of the transformation of logistics flows after 2022, changes in the structure of international transport, and the role of multimodal schemes in ensuring the sustainability of the transport system.

The reference period for the statistical study, 2015-2024, was selected to ensure a representative analysis of long-term structural changes based on complete and consolidated annual financial statements. The start of the period (2015) reflects the stabilisation of the transport sector following previous economic fluctuations. The end of the period (2024) marks the cut-off point for fully consolidated annual data from official international databases (such as Eurostat). However, to ensure the integration of up-to-date data, the study additionally includes operational data, interim reports and development trends for 2025-2026 in the "Results and Discussion" section. This time range allows to carry out comparative analysis of pre- and post-crisis changes in the transport system.

A comparative analysis was used to compare the functioning of Ukraine's transport system before and after changes to major international logistics routes. The comparison was based on criteria such as dominant modes of transport, the structure of logistics schemes, cargo flow directions, the role of border infrastructure, and the level of integration into the European Union's transport network. This made it possible to identify key trends in the development of multimodal transport and to determine promising directions for the modernisation of transport infrastructure. A specific comparative cross-national analysis was used to assess the use of railway transport within the multimodal logistics infrastructure of European countries. This analysis was carried out to evaluate the strategic transition towards environmentally sustainable transport solutions and to analyse the adaptability of continental supply chains. Railway transport was chosen exclusively as the central element of this comparison, as it serves as the operational basis for the EU-Ukraine "corridors of solidarity" and acts as the primary green alternative for alleviating bottlenecks in cross-border freight transport. The evaluation criteria are based on the share of rail transport by mode of transport (%) in the total volume of domestic freight transport. Chronology is specifically focused on the years 2014, 2023 and 2024. The year 2014 serves as a structural macro-historical baseline, marking the beginning of Ukraine's intensive economic integration with the EU and the onset of early regional geopolitical disturbances. The years 2023 and 2024 represent the most critical contemporary phase, encompassing a full-scale reorientation and stabilisation of international logistics corridors amidst extraordinary military and trade challenges.

Specific descriptive and structural statistical methods were used to process the statistical data and to assess the dynamics of transport processes. In particular, a time series analysis (dynamic analysis) was applied to assess changes in freight transport volumes and to track chronological transformations from 2015 to 2024. The analysis of structural shifts (assessment of the distribution of transport modes) was used to calculate the exact percentage share of different modes of transport, such as maritime, road and railway, in global and national logistics systems. Furthermore, methods of comparative statistical grouping and normalisation were employed to assess and visualise railway transport usage indicators for individual European countries in comparison with the European Union average. An analytical synthesis of these statistical indicators enabled the systematisation of logistics trends both before and after the turn of 2022. The empirical basis of the study consisted of finalised and operational data from key international and national transport institutions. Specifically, long-term indicators on freight volumes and modal shift trends were retrieved from the verified database of the Statistical Office of the European Union (Eurostat, 2026). The metrics regarding cross-border infrastructure capacity and the performance of alternative logistics routes were sourced from the official evaluation reports on the launch and expansion of the "Solidarity Lanes" initiative (European Commission, 2022). For the analysis of the Danube River corridor and the implementation of alternative maritime cluster models, industry-specific analytical resources and governmental monitoring data were utilised (Potaieva, 2026). These core sources provided a reliable foundation for capturing transport dynamics over the monitored timeframe.

To carry out a detailed comparative analysis of the efficiency of alternative multimodal freight corridors between Ukraine and the EU, the study used the method of relative normalisation and systematic generalisation of technical and economic parameters. The combined railway-road route via the border crossings of Poland and Slovakia was taken as the base index (100%) for financial costs. The relative indices for other means of transport were calculated using the formula (1):

$$I_{cost} = \left(\frac{C_x}{C_{base}}\right) \cdot 100\%, \qquad (1)$$

where C_x – absolute cost of shipping 1 TEU on the route under study, C_{base} – the average absolute cost of delivery via the standard railway-road route. The fluctuation ranges for direct road transport (145-160%) and the Danube River cluster (70-80%) have been established based on an analysis of data from logistics operators in the "Solidarity Lanes" reports (European Commission, 2022) and analytical studies (Samoiliuk & Polushkin, 2026). Delivery times are defined as the total "door-to-door" transportation time based on monitoring data from the UNHCR (n.d.). Carbon dioxide (CO_2) emission ranges (g/t-km) are integrated based on transport environmental matrices from the work of I. Derpich *et al.* (2024) and Eurostat (2026) reports.

The study analysed recent scientific publications on the development of multimodal transport systems, the digitalisation of logistics, and the integration of transport infrastructure into the TEN-T. In particular, it examined fundamental research on route optimisation (Taran *et al.*, 2023), modelling the operational efficiency of providers (Onyshchenko *et al.*, 2024), as well as the environmentalisation and decarbonisation of transportation (Derpich *et al.*, 2024). It also analysed concepts for the implementation of intelligent digital platforms in logistics (Berestenko & Onyshchenko, 2024; Fazi & Fransoo, 2025). Additionally, analytical studies on the development of logistics hubs, dry ports, and Ukraine's integration into the TEN-T were used.

Official analytical reports and centralised statistical datasets from European and national institutions formed the empirical backbone of this research. The chronological window for data collection spanned a ten-year interval from 2015 to 2024, ensuring internal consistency across the methodological sections and providing a sufficient baseline to trace structural transformations. The primary source of numeric datasets regarding intermodal distribution was the Eurostat (2026). This was cross-referenced with the European Commission's annual monitoring reports on the EU-Ukraine Solidarity Lanes (European Commission, 2022). The institutional framework of the study was substantiated through strategic national documentation, specifically Resolution of the Cabinet of Ministers of Ukraine No. 1550-2024-р (2024), which approved the National Transport Strategy of Ukraine for the Period up to 2030.

To substantiate suggestions for diversifying routes, actual data from specialised digital platforms, statistical dashboards, and transport monitorings were analysed. The operational characteristics of Solidarity Lanes were examined based on the official tracking portal of the European Commission (2022). The development status of the Moldova Motorway (A7 corridor) was assessed using the regional infrastructure platform Firtka (Liubchyk, 2024). Indicators of bilateral trade with Germany were derived from the macroeconomic database of the Centre for Economic Strategy (Samoiliuk & Polushkin, 2026). Furthermore, parameters regarding the operational capacity of the Danube and Baltic ports were evaluated based on the data from the integrated

Government Portal of Ukraine (Government Portal, 2026), the specialised agricultural analytics platform AgroTimes (Potaieva, 2026), and the international logistics media portal IntermodalNews EU (Zasiadko, 2022).

The criteria for selecting scientific sources included the relevance of the research, publication in specialised international journals, indexing in the Scopus and Web of Science scientometric databases, as well as alignment with the subject matter of multimodal transport and transport logistics. Particular attention was paid to sources published between 2022 and 2026, ensuring the relevance and scientific reliability of the research. The criteria for selecting specific case studies (Poland, Romania, Slovakia, and Bulgaria) as subjects for the analysis of logistics corridors were: the presence of shared land or sea borders with Ukraine, the dynamics of cross-border cooperation, and the strategic role of these countries in ensuring the uninterrupted export of Ukrainian agricultural products under conditions where traditional port infrastructure is blocked.

Results and Discussion

Multimodal transport helps to organise logistics efficiently, as it enables the transportation of goods over long distances using several modes of transport. Multimodal transport involves sea, motor, railway and air transport. Large consignments of commercial cargo are typically delivered by sea from distant countries – the USA, Canada, China and others. Goods are often shipped by sea from Europe. Air transport plays a key role in multimodal transport for the urgent delivery of cargo over long distances, ensuring maximum speed in the supply chain and increasing the flexibility of the logistics system. Although this mode of transport cannot be described as cheap, it is the optimal option for perishable and urgent cargo. Railways and automobile transport can serve as either auxiliary or primary modes of transport in mixed routes (Sloboda Region, 2022). The integration of different means of transport is based on uniform standards and a single information environment, both within the country and its regions, and in international traffic. Multimodality applies to transport infrastructure, vehicles, cargo units and management systems. The core concept of multimodality is transhipment and transit. Multimodality is characterised by the presence of hubs that connect networks of different modes of transport into a single large integrated network, where cargo is transferred from one means of transport to another.

The key feature of a multimodal transport system, as with any system, is its integrity and unity, which is achieved through specific interconnections and interactions between its constituent elements. The constituent elements of a multimodal transport system are: logistics flows; transport infrastructure; parties involved; and the regulatory framework. Multimodal transportations, carried out by logistics companies on behalf of businesses, are cost-effective and efficient in terms of increasing speed, ensuring safety and reducing transport costs. Logistics companies with considerable experience in this field develop optimal routes and choose the most efficient and suitable combinations of transport modes, loading and unloading points, and the necessary equipment for handling the specific product. This refers to all types of delivery, including containerised multimodal transport. The timely and correct preparation of the necessary documents significantly reduces the time lost due to delays caused by errors or the absence of required documents. Routes planning taking into account road and traffic conditions, knowledge of the particularities of sea and air ports, and other logistical factors, enables to respond promptly to potential obstacles and quickly redirect cargo. This flexibility in transportations allows to guarantee compliance with delivery deadlines and other terms of the agreement with the customer.

Different means of transport have different technical and operational characteristics and capabilities (Table 1). Multimodal systems allow each means of transport to develop its capabilities to meet the demand for specific transport services, which, as part of the overall demand for transport by all modes within the system, can be met by integrating one type of transport with another and through competition between interacting modes of transport (transport companies). Multimodality also involves digital logistics, which can be built on the basis of uniform rules and algorithms for the management, planning and operation of different transport modes. Multimodality also envisages digital logistics, which can be built on the basis of uniform rules and algorithms for the management, planning and operation of different modes of transport. In this context, the transition to "Freight Mobility as a Service" platforms acts as a critical catalyst for integrating regular rail and maritime schedules into open, transparent and synchronised multimodal chains (Fazi & Fransoo, 2025). The deployment of such digital systems creates a unified information environment, enabling operators and shippers to establish flexible "trade-off zones" that dynamically balance cost, speed and reliability of delivery during crisis-driven reorientations (Berestenko & Onyshchenko, 2024).

Table 1. The functional role of transport modes in multimodal transportations

Transport mode	Role in the logistics chain	Cargo characteristics	Advantages
Maritime	Main line (intercontinental)	Large shipments, commercial goods	Low cost per cargo unit
Air	Express delivery	Perishable, urgent, and costly freight	Maximum speed and flexibility
Railways	Main or auxiliary	Bulky freight, containers	Stability, weather independence
Motor transport	Auxiliary ("last mile") or main	A wide range (small and medium-sized batches)	Delivery "from door to door"

Source: compiled and systematised by the author based on O. Strelko *et al.* (2022), Sloboda Region (2022)

The European Union has an extensive network of multimodal logistics centres, which play a fundamental role in ensuring the efficiency and competitiveness of the region's transport system. The synchronisation of the operational activities of such centres depends to a large extent on advanced modelling algorithms for carrier selection and tactical route planning, as illustrated in the integrated framework proposed by S. Onyshchenko *et al.* (2024). Furthermore, the overall efficiency of combining road and railway transport segments in these networks depends on the dynamic allocation of freight transport to balance carriers' fixed and variable costs (Taran *et al.*, 2023). An analysis of the structure of freight transportation by means of transport within the global logistics system for the period 2015-2024 indicates the consistent dominance of maritime transport, which share fluctuates between 67% and 69%, confirming its key role in securing global trade flows (Table 2). Motor transport is showing gradual growth (from 22.5% to 25.7%), reflecting its increasing importance in regional and intra-continental transport. The share of railway transport remains relatively stable at 5.3-6.0%, indicating its steady but supporting role in the global transport system. At the same time, air transport retains a negligible share (around 0.2%), which is explained by the high cost of transport, but its importance remains significant for urgent and high-value cargo. Inland waterways account for a small share (1.6-2.1%), characterising them as a local element of multimodal logistics schemes.

Table 2. Percentage of transport modes for the period 2015-2024, %

Transport mode	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Air	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Railways	5.7	6.0	5.8	5.7	5.5	5.3	5.5	5.6	5.5	5.4
Motor transport	22.5	23.1	23.3	22.9	23.1	24.0	24.4	24.9	25.3	25.7
Maritime	69.5	68.7	68.8	69.4	69.4	68.8	68.1	67.7	67.4	67.0
Inland waterways	2.1	2.1	2.0	1.7	1.8	1.8	1.8	1.6	1.6	1.7

Source: developed by the author based on Eurostat (2026)

Building upon the general transport mode dynamics presented in Table 2, Figure 1 offers a deeper comparative insight into how specific countries perform in relation to the baseline EU average (100%).

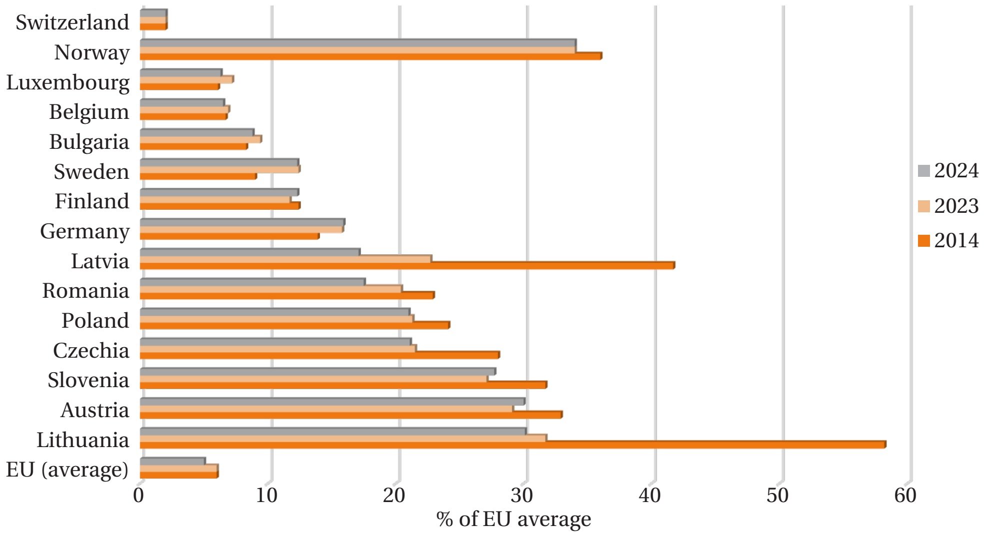

Figure 1. A comparative analysis of the use of railway transport in multimodal systems across European countries
Source: developed by the author based on Eurostat (2026)

The analysis was carried out to assess the transit resilience and environmental sustainability of European logistics chains, using the share of railway transport in the multimodal transport system as the main criterion. An analysis of the statistical data presented in Figure 1 allows to identify key trends in the development of multimodal transport systems in European countries. The horizontal axis (0-60) reflects the exact percentage (%) of railway transport in the total volume of freight transport for each country. A comparison of 2024 with the 2014 baseline shows that the share of railway transport in total freight transport has decreased in 17 of the 25 EU countries with railways. The choice of 2014 as a historical benchmark, compared with the recent period of 2023-2024, clearly highlights how long-term geopolitical realignments and immediate security crises are forcing structural shifts in logistics. Although the average share of railway transport in the EU remains low but relatively stable at 5.0-6.0% (confirming the continued dominance of road transport), the development trajectories of individual countries differ significantly. For example, the experience of Switzerland, where the share of railways remains stable at

34-36%, demonstrates an effective state strategy for shifting freight flows from motorways to railways. By contrast, the sharp decline in Lithuania (from 58.2% in 2014 to 30.1% in 2024) and Latvia (from 41.7% to 17.1%) highlights how the collapse of traditional post-Soviet transit corridors has led to a radical, crisis-driven restructuring of multimodal schemes towards Western European markets.

The most significant changes have been observed in Lithuania and Latvia. In particular, in Lithuania, the share of railway transport has almost fallen by half: from 58.2% in 2014 to 30.1% in 2024. A similar decline is also characteristic of Latvia (a drop from 41.7% to 17.1%). This is explained by the reorientation of transport corridors and changes in the geopolitical situation, which are forcing these countries to restructure their multimodal schemes toward Western European markets. Counties like Austria (30.0%), Slovenia (27.7%) and Czechia (21.1%) demonstrate a high and stable level of integration of the railway segment into logistics chains. This is due to both their geographical location (transit hubs) and the well-developed infrastructure of intermodal terminals.

The modest growth in the rail share in Germany (from 13.9% to 15.9%) and Sweden (from 9.0% to 12.3%) indicates the gradual implementation of the "Greening Transport" policy. For Ukraine, the experience of these countries is important in the context of developing its own algorithms for optimising multimodal transport, which will improve the efficiency of the logistics system and reduce the load on the highway network. The obtained results confirm that the modern global transport system is distinctly multimodal in nature, with the integration of maritime and motor transport with other modes of transport playing a leading role in ensuring the efficiency of logistics chains of essential goods, and support for Ukrainian exports via European ports (Sarahman, 2025).

To conduct a detailed assessment of the effectiveness of Ukraine's logistics system transformation after 2022, a comparative analysis has been carried out of key land and river multimodal routes to European Union countries. The assessment has been based on three key criteria: financial costs (cost of delivering 1 TEU), time (door-to-door transit time), and environmental impact (CO_2 emissions). The results of the analysis and comparison of logistics parameters for the "Central Ukraine – Central European Hub (Germany)" route are summarised in Table 3.

Table 3. Comparative analysis of the efficiency of logistics routes from Ukraine to the EU

Multimodal route (corridor)	Financial costs (per TEU)	Delivery time (days)	Emissions (CO_2) (g/t-km)	Major infrastructure constraint
Railway and road (via Poland/Slovakia)	100% (base level)	3-5	12-18	Congestion at border crossings, track gauge change (1,520/1,435 mm)
Direct road transport (via border crossings)	145-160%	2-4	62-80	Shortage of permits, long queues at the borders, high fuel costs
River-sea (Danube cluster) (via Romania/Bulgaria)	70-80%	8-12	5-10	Dependence on the dimensions of the navigation channel; limited capacity of the docks

Source: calculated and compiled by the author based on the normalisation methodology described in the "Materials and Methods" section (formula 1), using input data from I. Derpich *et al.* (2024), O. Potaieva (2026)

Based on an assessment of the effectiveness of existing transport schemes, it has been determined that road transport, despite its high speed and mobility, shows the lowest economic and environmental efficiency. It increases logistics costs by an average of 50% compared to combined railway schemes. At the same time, the Danube River Cluster ensures the greatest reduction in financial costs (20-30% cheaper than rail) and has the smallest carbon footprint, but it significantly loses out in delivery speed due to lengthy cargo transshipment operations at the ports of Izmail and Reni. Based on the comparison of the parameters of individual corridors, a comprehensive assessment of global changes across the entire transport system becomes possible. The general macro-logistics indicators of these transformations are presented in Table 4. To summarise the systemic changes in the operational paradigm of national logistics, a comparative matrix of macrostructural changes has been developed (Table 4). Although the quantitative statistical baseline of this study remains tied to the period 2015-2024 due to the availability of consolidated annual datasets, the qualitative assessment of transformations after 2022 is projected to extend to the period 2025-2026. This enables the study to contextually cover the final integration benchmarks, the medium-term outcomes of the evolutionary phases of the "Solidarity Corridors", and the current institutional reorientation towards the TEN-T framework. The synthesis is based on the regulatory frameworks of the Resolution of the Cabinet of Ministers of Ukraine No. 1550-2024-p (2024), the European Commission's strategic assessment documents (2022) and recent transport capacity models proposed by sectoral researchers (Berestenko & Onyshchenko, 2024; Derpich *et al.*, 2024).

Table 4. Transformation of Ukraine's transport system (before and after 2022)

Indicator	Before 2022 (2014-2021)	After 2022 (2022-2026)	The trend
Main export route	Seaports of the Black Sea	Overland and Danube routes	Relocation to the EU
The predominant mode of transport	Maritime + railway	Automobile + railway + multimodal	Multimodality
Logistics structure	Linear	Networking	Decentralisation

Table 4. Continued

Indicator	Before 2022 (2014-2021)	After 2022 (2022-2026)	The trend
The role of the EU	Restricted	Key (Solidarity Lanes)	Integration
Risks	Low	High (war)	The growth of risk management

Source: compiled and structured by the author based on European Commission (2022), Resolution of the Cabinet of Ministers of Ukraine No. 1550-2024-p (2024), V. Berestenko & S. Onyshchenko (2024)

During the period up to 2022, the system was primarily focused towards maritime transport via Black Sea ports and was characterised by relative stability and a centralised logistics structure. After 2022, there was a shift towards motorway, railway and multimodal transport, with a focus on land corridors to EU countries. Following Russia's invasion of Ukraine and its blockade of Ukrainian ports, Ukrainian grain and other agricultural goods could no longer reach their destinations. The situation threatened global food security, and there was an urgent need to establish alternative logistics routes utilising all relevant modes of transport. It would not be an exaggeration to say that a key step in supporting the export of Ukrainian agricultural produce and the import of critical goods amid the blockade of seaports was the launch on 12 May 2022 of the EU's "Solidarity Lanes" initiative, designed to enable Ukraine to export grain and import essential goods, ranging from humanitarian aid to animal food and fertilisers (Table 5). The specified logistics routes include rail, road, and river routes through neighbouring EU countries – Poland, Romania, Slovakia, and Hungary – and have become critically important for the Ukrainian economy (European Commission, 2022). The structural integration and survival of Ukraine's foreign trade under wartime restrictions were largely supported by coordinated institutional actions at the transnational level. To monitor the operational vectors and strategic outcomes of these measures, Table 5 presents an overview of the main logistics corridors and emergency programmes deployed by international partners. The operational objectives, timelines and logistical impact of these initiatives were structured based on a systematic assessment of the European Commission's Communication on Solidarity Lanes (European Commission, 2022), assessments of global supply chain adaptation by M. Samoiliuk & H. Polushkin (2026), and sectoral monitoring reports on western border dry ports and maritime clusters (Zasiadko, 2022).

Table 5. Key EU logistics initiatives for Ukraine during the war

Initiative	Launch period	Objective	Means of transport	Significance
"EU Solidarity Lanes"	12.05.2022	Alternative export/import routes in the context of port blockades	Railway, motorway, river	Crucial channel for grain exports and imports of goods
Transit expansion through the EU	2022 – present	Providing access to EU ports	Railway, motorway	Supports for agricultural exports
The use of EU ports	2022 – present	Transhipment of Ukrainian goods	Maritime + multimodal	Expansion into global markets

Source: compiled and structured by the author based on European Commission (2022), M. Zasiadko (2022), M. Samoiliuk & H. Polushkin (2026)

The construction of the Moldova Motorway is underway in Romania. The new transport corridor will link southern Romania (Ploiești) with the north-eastern part of the country, partly following Pan-European Corridor IX. It will pass through Buzău, Focșani, Bacău, Roman, Pașcani and Suceava, connecting with the Ukrainian M19 motorway near the Siret River and the Chernivtsi region. Thanks to this route, Ukraine could gain a new European transport corridor. In the future, this motorway could provide Ukraine with access to Romanian ports. Furthermore, it will create an alternative route to EU countries, allowing traffic to bypass Poland, Hungary and Slovakia. The route via Siret and through Romania has become one of the largest transit routes for transporting grain from Ukraine by land following the full-scale Russian invasion. Currently, around 3,000 workers are working on the motorway 24/7. To avoid losing European funding, work on the A7 motorway must be completed by 2027 (Liubchyk, 2024).

Germany is a significant partner on Ukraine's course to EU membership. The Federal Republic of Germany is helping to ensure that the economy of a country, which is subjected to attacks by Russian drones almost every night, remains in relatively good shape. Although Ukraine is not yet an EU member, both countries are already cooperating in all four areas of the single market: trade, services, people and capital. Bilateral trade in goods alone reached a record high in 2025, whilst relations in the areas of services, labour and investment continued to deepen. According to preliminary data, trade volume in 2025 amounted to €12.4 billion, which is 52% higher than the trade volume between Russia and Germany. This relationship is not one-sided: Ukraine is of great importance to Germany's supply chains and labour market, just as Germany remains one of Ukraine's most important economic partners. Germany has a trade surplus with Ukraine. Before the war, German exports to Ukraine consisted mainly of cars and lorries, medicines and agricultural machinery. Since 2022, the structure of exports has changed significantly: Germany now exports primarily defence and military products. Ukraine has become an important market for these highly technological goods, which often have dual-use applications (Samoiliuk & Polushkin, 2026).

Ukraine's airspace remains closed for civil aviation due to ongoing military threats, which means that cross-border freight transport between Germany and Ukraine relies exclusively on land and multimodal land corridors (Safe Airspace, n.d.). Road transport serves as the primary operational option at this stage. Shipments from Germany via this route account for the majority of transport, providing crucial logistical flexibility. Remarkably, Germany is one of the leading suppliers of high-quality equipment for energy infrastructure, including industrial generators, heavy transformers and energy storage systems – components that remain vital for stabilising the resilience of Ukraine's power grid against the backdrop of systematic attacks on its civilian energy infrastructure (Samoiliuk & Polushkin, 2026). At the same time, the Port of Hamburg (Germany) plays a crucial role in these supply chains, ranking among Europe's leading container hubs with an annual throughput that has historically fluctuated around 8-9 million TEU (Port of Hamburg, 2026). Hamburg's distinctiveness lies in its extensive and highly integrated network of port railways (Hafenbahn), which facilitates rapid inland intermodal connections throughout Central and Eastern Europe. Modern container terminals within the hub are equipped with automated cargo handling and synchronous tracking systems, providing a strategic blueprint for the sustainable diversification of corridors (Zasiadko, 2022).

Ukrainian-Slovak cross-border cooperation began with Slovakia's accession to the EU. The main participants in cross-border cooperation between Ukraine and Slovakia are the Zakarpattia region (Ukraine) and Prešov and Košice (Slovakia). As part of this cross-border cooperation, the Ukrainian-Slovak Business Council was established to monitor, provide recommendations and make decisions aimed at improving cooperation between the parties. The creation of this Council enables the swift resolution of various issues, as well as the development of a further action plan to achieve the medium-term goals of deepening cross-border cooperation. In recent years, particular attention in bilateral scientific and technical projects between Ukraine and Slovakia has been focused on the development of devices and technologies for the safe and environmentally friendly use of natural resources, as well as energy-efficient management. On the whole, despite the positive dynamics of bilateral political and trade-economic relations, problematic issues remain between Ukraine and Slovakia. These include asymmetry in political interaction (however, with the start of Russia's full-scale invasion of Ukraine, Ukrainian diplomacy has become more active, particularly in terms of cooperation with Bratislava); the uneven investment activity of both Ukraine and Slovakia; the presence of unresolved issues regarding the Slovak diaspora in Ukraine, and so on. Nevertheless, the positive aspects of Ukrainian-Slovak cooperation still prevail. In particular, this is due to the intensification of cooperation in the fields of science, education and innovations. With the support of the EU and various European programmes and initiatives, cross-border cooperation between the two countries has been further strengthened, and this is likely to become even more robust following Ukraine's victory in the war currently raging across Europe (Balanchuk & Sokolovska, 2024).

Within the framework of modern border logistics, the transport corridor between Slovakia and Ukraine serves as a key channel for the import and export of goods to the EU, supported by a highly integrated road and railway infrastructure. The main land gateway for these operations is the "Uzhhorod – Vyshne Nemetske" border crossing point, where standard delivery times for freight typically range from 1 to 3 days in accordance with coordinated customs procedures (UNHCR, n.d.). At the same time, freight transport between Ukraine and Poland remains a cornerstone of regional supply chain management, developing rapidly thanks to geographical proximity, deep economic integration and well-established bilateral trade channels. For many operational supply chains, particularly those handling often small batches and industrial parcels, rapid cross-border delivery is vital for business continuity. However, the operational environment at the Ukrainian-Polish border has faced periods of extreme strain, characterised by serious truck blockages and technical bottlenecks at major road checkpoints (Samoiliuk & Polushkin, 2026). Despite these logistical crises and temporary restrictions, Poland has consistently maintained its position as one of Ukraine's key strategic and economic partners within the EU, contributing to the long-term stabilisation of land-based trade flows (Zasiadko, 2022).

It is worth mentioning that cooperation with Poland in the field of transport and logistics has become particularly relevant at present, during Russia's armed aggression against Ukraine, when significant problems have arisen in organising foreign trade logistics due to the blockade of seaports. The Polish route is becoming essential for Ukrainian exports from a logistics perspective due to the blockade of Black Sea ports. In other words, new opportunities and prospects have emerged for cooperation with Poland as a strategic partner. For example, the Polish seaport of Kolobrzeg, located on the Baltic Sea coast between Świnoujście and Gdynia, is offering to handle the transhipment of Ukrainian agricultural exports at its facilities. Several pilot projects have already been launched. In addition, Ukraine and Poland have signed a memorandum on strengthening bilateral cooperation in the field of rail transport, under which the establishment of a joint logistics enterprise is planned. This, in turn, will enable a significant increase in the volume of railway transport of Ukrainian exports to the EU and to global markets via Europe. The Polish Ministry of Economic Development and Technology and the Ukrainian Ministry of Economy have signed a Memorandum regarding the development of trade facilitation tools. The aim of the agreement is to strengthen bilateral economic cooperation by simplifying trade, with a focus on ensuring insurance coverage for the supply of goods and services (Trushkina, 2022).

Economic cooperation between Ukraine and Bulgaria focuses on integration into the European area, the development of alternative logistics routes and the strengthening of security in the Black Sea. A key area of logistics here is the launch of direct passenger rail routes (via Romania), which will help to strengthen Ukraine's integration with the European transport space, develop the Danube cluster and coordinate road transport (Fig. 2). The governments of Ukraine and Bulgaria have reached an agreement on establishing the transport of agricultural products from Ukraine via Bulgarian ports on the Black Sea coast. Bulgaria plays an important role for Ukrainian exporters, particularly in new supply chains and the export of fuel and agricultural raw materials, and is one of the largest suppliers of diesel fuel to Ukraine, providing a significant proportion of the country's needs, notably through oil refinement at a local plant. In order to strengthen the region's energy security, Ukraine and Bulgaria are also developing the "Vertical Gas Corridor". The country also serves as a hub for infrastructure restoration and the development of transport corridors, particularly railway connections, which strengthens Ukraine's integration into the European transport area. The port of Varna is regarded as a key logistics hub (Government Portal, 2026).

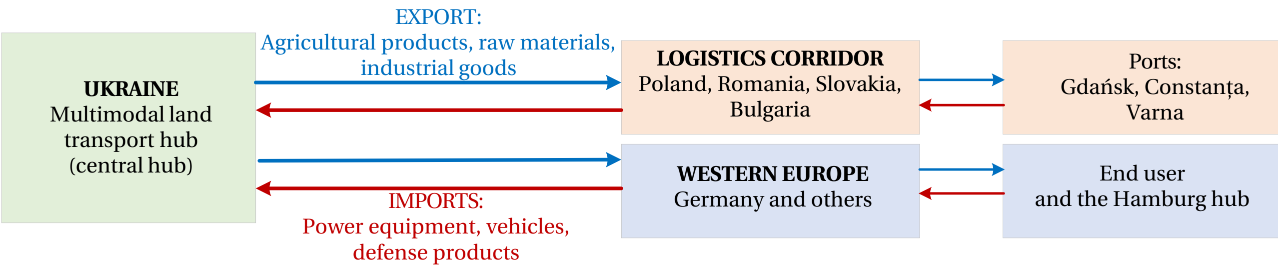

Figure 2. Integrated model of trade and logistics flows

Source: compiled and structured by the author based on N. Trushkina (2022), European Commission (2022), M. Zasiadko (2022), I. Balanchuk & N. Sokolovska (2024), Government Portal (2026)

Figure 2 demonstrates the current structure of international freight flows, shaped by the transformation of Ukraine's transport system following 2022 and the shift towards European logistics routes. Economic cooperation between Ukraine and Bulgaria is focused on integration into the European space and the development of alternative logistics routes in the Black Sea region. A key direction is the development of the Danube cluster and the launch of direct passenger and freight railway routes through the territory of Romania (Government Portal, 2026). Bulgaria plays a significant role in ensuring Ukraine's energy security, being one of the largest suppliers of diesel fuel (Cabinet of Ministers of Ukraine, 2024). In addition, agreements have been reached on the use of Bulgarian Black Sea ports (in particular, the Port of Varna, which is a key logistics hub) for the export of Ukrainian agricultural raw materials (Zasiadko, 2022). The countries are also actively developing the "Vertical Gas Corridor" project, which strengthens Ukraine's integration into the European transport and energy network (Reuters, 2024). The core of the model identifies Ukraine as a key transit and logistics hub facilitating interaction between domestic producers and European Union countries. This emphasises the changing functional role of the national transport system – shifting from a focus on maritime exports to the development of a multimodal land-based transit hub. Export flows are directed towards EU countries (Poland, Romania, Slovakia, Bulgaria), which serve as a border logistics belt and ensure the further transportation of goods to major European hubs, notably Germany and the ports of Hamburg, Gdańsk, Constanța and Varna. Imports are mainly agricultural products, raw materials and industrial goods.

The import flows run in the opposite direction and originate mainly from leading EU countries, primarily Germany and Poland. They include supplies of energy equipment, vehicles, defence and high-tech products, which ensure the functioning of Ukraine's critical infrastructure. An important element of the scheme is the logistics infrastructure, which includes border crossings, the network of EU logistics hubs and integration into the TEN-T. This is evidence of the steady harmonisation of Ukraine's transport system with European standards and the strengthening of intermodal transport. The development of a network of dry ports along Ukraine's western borders is becoming a strategic priority, as it enables the transformation of the border "belt" from a logistical bottleneck into powerful multimodal hubs for transshipping cargo from the Ukrainian gauge (1,520 mm) to the European gauge (1,435 mm) (Derpich *et al.*, 2024). This, in turn, ensures the continuity of supply chains within the "Solidarity Lanes" initiative and strengthens the national economy's resilience to external challenges (European Commission, 2022). This approach allows for a significant increase in the capacity of border infrastructure, reduces cargo processing time, and mitigates logistics risks arising at border crossing points. The formation of a dry port network also facilitates the redistribution of cargo flows from congested road routes to more efficient railway and intermodal corridors. One of the priority areas for enhancing the resilience of Ukraine's export and import routes is the implementation of a pilot project to develop the Danube Transport and Logistics Cluster. Initiated by the Ministry of Community and Territorial Development of Ukraine, this project aims to create competitive conditions for the stevedoring business and integrate river infrastructure into the EU's single logistics space (Potaieva, 2026).

The integration of Ukraine's river and railway infrastructure into the TEN-T network enhances the interoperability of transport systems and contributes to the creation of a single European logistics area, which is a key factor in the long-term competitiveness of the Ukrainian economy (Table 6). The structural components of this modernisation system, including targeted tariff adjustments and the centralisation of port assets, have been systematised on the basis of strategic development plans issued by the Ministry of Community and Territorial Development of Ukraine. This matrix also includes institutional roadmaps for the synchronisation of the Danube cluster, as assessed in regional logistics studies (Potaieva, 2026), and reports on operational infrastructure from specialised transport platforms (Zasiadko, 2022).

Table 6. Key instruments for modernising the Danube corridor

Modernisation area	Content of the measure	Expected effect
Financial incentives	Reinvestment of state enterprise profits and targeted allocation of port fees	Modernisation of port infrastructure and fleet renewal
Tariff policy optimisation	Compensation mechanisms for rail transport to the ports of Izmail and Reni	Reduction of logistics costs and increased route competitiveness
Institutional centralisation	Establishment of a unified Danube branch of the SE "USPA"	Optimisation of asset management and resource centralisation
Industrial hub formation	Establishment of industrial parks based on ports and PJSC "UDP"	Capital attraction, employment growth, and stable cargo flow

Source: compiled and structured by the author based on M. Zasiadko (2022), O. Potaieva (2026), UNHCR (n.d.)

According to forecasts, the implementation of these measures will ensure a guaranteed cargo flow of up to 2.5 million tons per year and preserve over 5,500 jobs in the maritime complex and Joint Stock Company "Ukrzaliznytsia" (Potaieva, 2026). From the viewpoint of international logistics, the development of the Danube cluster is of paramount importance for deepening Ukraine's integration into the TEN-T. These efforts provide the basis for establishing sustainable intermodal supply chains linking Ukrainian manufacturers with countries in the Danube basin and strategic European markets. Therefore, Ukraine serves as a transit hub, the countries of Central and Eastern Europe act as a cross-border transport corridor, and Western Europe functions as the final distribution and consumer market.

The contemporary structural transformation of Ukraine's freight transport system post-2022 and the accelerated roll-out of multimodal corridors require in-depth academic analysis through comparison with existing scientific discourse. The results obtained in this study regarding route optimisation, digitalisation tools, and the adaptation of regional infrastructure demonstrate both strategic alignment and significant differences from previously established models. In their study, I. Taran *et al.* (2023) established a mathematical relationship between optimisation criteria and total delivery volumes, and proposed algorithms for synchronising the discrete stages of the multimodal process. Their assertion that splitting large consignments allows for flexible adjustment of carriers' variable costs clearly correlates with the results of this study. In particular, analysis of the rail-road route through Poland and Slovakia confirms that the tactical splitting of consignments helps to mitigate infrastructure constraints associated with the change in rail gauge from 1,520 mm to 1,435 mm. Similarly, S. Onyshchenko *et al.* (2024) developed a comprehensive economic-mathematical model for coordinating road, railway and sea transport schedules with the aim of minimising costs under regional constraints. Their focus on inter-provider coordination serves as the theoretical basis for the integrated model of trade and logistics flows proposed in this work. However, whereas their model relies on stable hub capacity, presented results demonstrate that under extreme conditions the effectiveness of such coordination critically depends on unpredictable border congestion, which requires the formation of dynamic "compromise zones" rather than rigid schedule planning.

The conceptual application of such flexible zones in the context of logistical crises expands upon the academic approaches proposed by V. Berestenko & S. Onyshchenko (2024). The authors substantiated that a flexible approach and dynamic balancing of customer requirements regarding speed, cost and reliability should become the operator's primary tool. This position is fully confirmed by presented findings regarding the Danube cluster's river-sea route. Although this corridor offers a unique reduction in financial costs of 20-30% and has the lowest carbon footprint (5-10 g/t-km), it is significantly slower in terms of delivery time (8-12 days). Thus, this study empirically confirms that the Danube route is a classic "trade-off zone", where shippers consciously exchange delivery time for economic and environmental benefits.

With regard to the environmental aspect, I. Derpich *et al.* (2024) have mathematically demonstrated that an excessive concentration of intermediate logistics hubs in conditions of high transit density is economically and environmentally inefficient. This statement differs somewhat from the current situation observed on Ukraine's western border. The study shows that the high density of border "dry ports" is not a source of inefficiency, but a strategic necessity for transforming logistical bottlenecks into powerful multimodal hubs. The pressing operational need to adapt to the blockage of traditional routes justifies the decentralised logistics structure. Moreover, N. Tyukhtenko (2024) systematised the technical, infrastructural and organisational components of logistics, emphasising the priority of adapting the national network to European TEN-T standards. Presented structural analysis of the tools for modernising the Danube Corridor strongly supports this view. The transition to institutional centralisation and the optimisation of tariff policy directly implements the integration priorities outlined by N. Tyukhtenko, demonstrating that infrastructure harmonisation is a prerequisite for the post-war resilience of the economy. The socio-economic developments highlighted in this study also reflect the findings of O.V. Svychynska & A.V. Reznyk (2025), who examined the dynamics of market recovery through railway optimisation and the resumption of container transport. However, whilst they focused primarily on internal market survival strategies and overcoming labour shortages, this study examines another aspect of the problem. This study assessed the transformation of the national system into a macro-regional transit hub linking the end markets of Western Europe (e.g., the Hamburg hub) with alternative ports on the Black and Baltic Seas.

From a global operational perspective, S. Fazi & J.C. Fransoo (2025) proposed the concept of FMaaS to scale up synchronous multimodal transport, arguing that the fragmentation of service offerings hinders practical multimodality. Whereas their theoretical model promotes open digital platforms in stable market conditions, this empirical data show that in crisis-hit regions, multimodality is achieved not only through digitalisation, but primarily through physical infrastructure diversification, such as the construction of the "Moldovan Motorwa" (A7 corridor) in Romania. Finally, V. Puzikova (2024) examined the dual nature of Ukraine's transit potential, highlighting the catastrophic disruption of traditional supply chains, where railways and seaports had historically accounted for up to 75% of foreign trade. V. Puzikova structural baseline fully confirms the historical shift recorded in this comparative matrix. This study expands on this idea, demonstrating that the transition from a linear, sea-dependent structure to a decentralised land-based network is no longer a temporary survival measure, but a sustained trend towards Ukraine's long-term integration into the European economic space.

The study has therefore identified the key trends in the development of Ukraine's transport system after 2022, which involve a shift towards multimodal and decentralised logistics models in response to European integration processes and military challenges. An analysis of how multimodal logistics systems operate has shown that their effectiveness is determined by a combination of route optimisation, digitalisation and infrastructure adaptation, taking into account crisis-related constraints and border instability. The prospects for modernising the transport system are linked to Ukraine's further integration into the European logistics space, the development of flexible intermodal corridors and the formation of a sustainable macro-regional transit hub.

Conclusions

This study revealed that Ukraine has significant potential to expand its participation in international and transit freight transport. An analysis of existing approaches to organising multimodal transport has shown that their effectiveness largely depends on the level of integration of the transport system, the coordination of interaction between modes of transport, and the degree of digitisation of logistics processes. Furthermore, an analysis of global market trends has confirmed the stable leading role of maritime transport and the steady growth of the road transport segment at the regional level, while the railway component in most European countries continues to show relatively low performance.

It has been determined that the key areas for improving the efficiency of multimodal transport are the optimisation of traffic flows, the reduction of cargo transshipment times, the reduction of logistics costs, and the improvement of delivery reliability. An important outcome of the study is the justification of the need to create an integrated transport environment focused on European Union standards, which involves harmonising the regulatory framework and developing infrastructure compatibility. It has been established that the introduction of intelligent transportation systems, electronic document management, and freight flow management platforms create the conditions for improving the transparency, manageability, and efficiency of logistics processes. It has also been demonstrated that multimodal logistics schemes help reduce the negative impact of transport on the environment through the rational selection of routes and the wider use of energy-efficient modes of transport. Prospects for further research include an in-depth analysis of the digital transformation of multimodal transport, an assessment of its economic efficiency in the context of the post-war reconstruction of Ukraine's transport system, and the development of adaptive models for managing logistics flows. Additionally, they involve mathematical modelling of risks in multimodal transport and the implementation of intelligent digital platforms based on artificial intelligence for dynamic management of cargo flows in crisis conditions.

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References

[1] Balanchuk, I., & Sokolovska, N. (2024). Ukrainian-Slovak cross-border cooperation: Bilateral programmes and projects in the field of science and technology. *Science, Technology, Innovation*, 2(30), 50-58. doi: 10.35668/2520-6524-2024-2-07.

[2] Berestenko, V., & Onyshchenko, S. (2024). Defining compromise area in the processes of multimodal delivery organization within the agile approach. *Eastern-European Journal of Enterprise Technologies*, 1(3(127)), 78-86. doi: 10.15587/1729-4061.2024.298846.

[3] Cabinet of Ministers of Ukraine. (2024). *Deepening cooperation in the energy sector: Ministers of Energy of Ukraine and Bulgaria signed a Memorandum*. Retrieved from https://surli.cc/mencma.
[4] Cherednichenko, K., Ivannikova, V., Sokolova, O., & Yanchuk, M. (2023). Model of transport safety assessment in multimodal transportation systems. *Transport*, 38(4), 204-213. doi: 10.3846/transport.2023.20865.
[5] Derpich, I., Duran, C., Carrasco, R., Moreno, F., Fernandez-Campusano, C., & Espinosa-Leal, L. (2024). Pursuing optimization using multimodal transportation system: A strategic approach to minimizing costs and CO_2 emissions. *Journal of Marine Science and Engineering*, 12(6), article number 976. doi: 10.3390/jmse12060976.
[6] European Commission. (2022). *Commission to establish Solidarity Lanes to help Ukraine export agricultural goods*. Retrieved from https://surl.li/ezvfsz.
[7] Eurostat. (2026). *Freight transport statistics – modal split*. Retrieved from https://surl.lu/cdhtxu.
[8] Fazi, S., & Fransoo, J.C. (2025). Freight mobility as a service: Open platforms for synchromodal transport. *Transportation Research Part E: Logistics and Transportation Review*, 204, article number 104368. doi: 10.1016/j.tre.2025.104368.
[9] Government Portal. (2026). *Ukraine and Bulgaria have agreed on priorities for transport cooperation*. Retrieved from https://www.kmu.gov.ua/news/ukraina-ta-bolhariia-uzghodyly-priorytety-transportnoi-spivpratsi.
[10] Gupta, J., Khobragade, V.J., & Upadhyay, R.K. (2024). Enhancing multimodal transportation in India: Jogighopa multimodal logistics park. In R.K. Upadhyay, S.K. Sharma & V. Kumar (Eds.), *Intelligent transportation system and advanced technology. energy, environment, and sustainability* (pp. 123-157). Singapore: Springer. doi: 10.1007/978-981-97-0515-3_7.
[11] Kalicheva, N., Solomnikov, I., & Kubinsky, A. (2022). Creation of a multimodal transport and logistics center: Problems and prospects. *Market Infrastructure*, 68, 35-38. doi: 10.32782/infrastruct68-6.
[12] Karam, A., Jensen, A.J.K., & Hussein, M. (2023). Analysis of the barriers to multimodal freight transport and their mitigation strategies. *European Transport Research Review*, 15, article number 43(2023). doi: 10.1186/s12544-023-00614-0.
[13] Kurniawan, D. (2024). Multimodal logistics for resilient and sustainable global supply chains: Strategic insights from integrated transport systems. *Sinergi International Journal of Logistics*, 2(4), 213-224. doi: 10.61194/sijl.v2i4.731.
[14] Liubchyk, T. (2024). *From Bucharest to Bukovyna: Ukraine will get a new European transport corridor*. Retrieved from https://surl.li/jrhiig.
[15] Lomotko, D.V., & Prymachenko, H.O. (2023). Analysis of the development of multimodal rail transport in Ukraine. *Rail Transport in Ukraine*, 2, 15-30. doi: 10.34029/2311-4061-2023-147-2-15-30.
[16] Okyere, S., Yang, J., & Adams, C.A. (2022). Optimizing the sustainable multimodal freight transport and logistics system based on the genetic algorithm. *Sustainability*, 14(18), article number 11577. doi: 10.3390/su141811577.
[17] Onyshchenko, S., Berestenko, V., Melnyk, O., Onishchenko, O., Fomin, O., Kravchenko, O., & Demidiuk, O. (2024). Integrated optimization models for carrier selection and route planning in multimodal transport systems. *Scientific Journal of Silesian University of Technology. Series Transport*, 125, 213-228. doi: 10.20858/sjsutst.2024.125.14.
[18] Orozonova, A., Gapurbaeva, S., Kydykov, A., Prokopenko, O., Prause, G., & Lytvynenko, S. (2022). Application of smart logistics technologies in the organization of multimodal cargo delivery. *Transportation Research Procedia*, 63, 1192-1198. doi: 10.1016/j.trpro.2022.06.124.
[19] Port of Hamburg. (2026). *Port of Hamburg: Throughput figures for 2025 at a glance*. Retrieved from https://www.hafen-hamburg.de/en/press1/news/hamburger-hafen-umschlagszahlen-2025-auf-einen-blick/.
[20] Potaieva, O. (2026). *Danube ports will operate under an experimental model*. Retrieved from https://agrotimes.ua/elevator/dunajski-porty-praczyuvatymut-za-eksperymentalnoyu-modellyu/.
[21] Puzikova, V. (2024). The development of the transit potential of Ukraine: Multimodal transportation and custom issues. *Customs Scientific Journal*, 1, 96-102. doi: 10.32782/2308-6971/2024.1.11.
[22] Resolution of the Cabinet of Ministers of Ukraine No. 1550-2024-p "On the Approval of the National Transport Strategy of Ukraine for the Period up to 2030 and the Adoption of the Operational Plan for its Implementation in 2025-2027". (2024, December). Retrieved from https://zakon.rada.gov.ua/laws/show/1550-2024-%D0%BF#Text.
[23] Reuters. (2024). *Ukraine, Moldova, Slovakia join Vertical Corridor for European gas transportation*. Retrieved from https://www.reuters.com/business/energy/ukraine-moldova-slovakia-join-vertical-corridor-european-gas-transportation-2024-01-19/.
[24] Safe Airspace. (n.d.). *Ukraine. Flight risk & conflict zone database*. Retrieved from https://safeairspace.net/ukraine/.
[25] Samoiliuk, M., & Polushkin, H. (2026). *German-Ukrainian trade reached record levels during the war*. Retrieved from https://ces.org.ua/germany-and-ukraine-trade.
[26] Samsonkin, V., Myronenko, V., Bulgakova, I., Shcherbyna, R., Yurchenko, O., & Pohorilyi, O. (2022). Multimodal logistics solutions in the conditions of incidental situations and threats to transport safety. In *Logistics systems: Technological and economic aspects of efficiency* (pp. 3-37). Kharkiv: Technology Center PC. doi: 10.15587/978-617-7319-66-4.ch1.
[27] Sarahman, O. (2025). Innovative solutions in transport process management: Ukrainian and European experience. *Economic Achievements: Prospects and Innovations*. doi: 10.5281/zenodo.17232717.

[28] Shuaibu, A.S., Mahmoud, A.S., & Sheltami, T.R. (2025). A review of last-mile delivery optimization: Strategies, technologies, drone integration, and future trends. *Drones*, 9(3), article number 158. doi: 10.3390/drones9030158.
[29] Sloboda Region. (2022). *Multimodal transport: Peculiarities*. Retrieved from https://surl.lu/bhtrgx.
[30] Strelko, O., Yurchenko, O., Vasilova, H., Gusar, I., & Rudiuk, M. (2022). Theoretical prerequisites for the development of multimodal transport-logistic technologies in cooperation with TEN-T network. In M. Nechyporuk, V. Pavlikov & D. Kritskiy (Eds.), *Integrated computer technologies in mechanical engineering – 2021* (vol. 367, pp. 1041-1050). Cham: Springer. doi: 10.1007/978-3-030-94259-5_80.
[31] Svychynska, O.V., & Reznyk, A.V. (2025). Analysis of the current state and prospects for the development of Ukraine's logistics market. *Municipal Economy of Cities*, 3(191), 636-642. doi: 10.33042/2522-1809-2025-3-191-636-642.
[32] Taran, I., Olzhabayeva, R., Oliskevych, M., & Danchuk, V. (2023). Structural optimization of multimodal routes for cargo delivery. *Archives of Transport*, 67(3), 49-70. doi: 10.5604/01.3001.0053.7076.
[33] Trushkina, N. (2022). Organisational forms of partnership and cooperation between Poland and Ukraine in the field of transport logistics in the context of war. In D. Nascimento & G. Starchenko (Eds.), *International partnership and cooperation of Ukraine in wartime. Collective monograph* (pp. 37-39). Portugal-Chernihiv: REICST. doi: 10.54929/monograph-02-2022-01-03.
[34] Tyukhtenko, N. (2024). Topical issues of formation transport and logistics infrastructure of Ukraine in the conditions of European integration and global challenges of today. *Economic Sustainability and Business Practices*, 1(1), 9-16. doi: 10.21272/esbp.2024.3-02.
[35] UNHCR. (n.d.). *Border monitoring*. Retrieved from https://www.unhcr.org/ua/en/border-monitorings.
[36] Zasiadko, M. (2022). *Bulgaria offers Port of Varna as logistics hub for Ukrainian export goods*. Retrieved from https://intermodalnews.eu/2022/05/03/bulgaria-offers-port-of-varna-as-logistics-hub-for-ukrainian-export-goods/.

Розвиток існуючих та нових мультимодальних логістичних схем як усталена тенденція для транспортної системи України

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Анотація. Сучасна трансформація міжнародних транспортних коридорів, блокування морських шляхів та переорієнтація логістичних потоків України зумовлюють необхідність розвитку ефективних мультимодальних транспортних систем та інтеграції до європейського логістичного простору. Метою статті було дослідження сучасних тенденцій розвитку транспортної системи України, аналіз функціонування мультимодальних логістичних схем та визначення перспектив їх модернізації в умовах євроінтеграції та воєнних викликів. В дослідженні були використані методи системного аналізу, порівняльного аналізу, статистичного оцінювання та узагальнення наукових джерел, аналітичних звітів і статистичних даних міжнародних організацій. Встановлено, що після 2022 року транспортна система України зазнала суттєвої трансформації, пов'язаної зі зміною основних напрямків вантажопотоків та формуванням нових мультимодальних маршрутів через країни Європейського Союзу. Досліджено досвід європейських країн щодо оптимізації взаємодії різних видів транспорту та стимулювання екологічно безпечного залізничного сегмента. Проведений аналіз показав зростання значення сухих портів, прикордонних логістичних хабів і Дунайського транспортного кластеру для підтримки безперервності міжнародних ланцюгів постачання. Встановлено, що інтеграція мультимодальних схем із цифровими технологіями управління логістикою, системами моніторингу вантажопотоків та інструментами оптимізації маршрутів сприяє підвищенню стійкості транспортної системи, скороченню логістичних витрат і мінімізації ризиків. Також доведено, що розвиток мультимодальної інфраструктури та гармонізація транспортної системи України зі стандартами TEN-T є необхідною умовою зміцнення транзитного потенціалу держави та її інтеграції до європейського економічного простору. Практичне значення отриманих результатів полягає у можливості їх використання під час формування державної транспортної політики, модернізації логістичної інфраструктури, розвитку міжнародних транспортних коридорів та оптимізації мультимодальних перевезень в Україні

Ключові слова: ланцюги постачання; мультимодальні технології; транспортні послуги; економічні партнери; вантажні перевезення