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OPTIMIZATION OF UKRAINE–EU LOGISTICS ROUTES UNDER WARTIME RISKS

Danylo Grabovsky, Dmytro Bugayko. "Optimization of Ukraine–EU Logistics Routes Under Wartime Risks". *The full-scale war has fundamentally transformed freight flows between Ukraine and the European Union, restricted the use of traditional maritime routes, and substantially increased pressure on road, rail, and inland waterway corridors. Under these conditions, logistics route selection cannot be based solely on minimizing distance or transportation costs. It must also account for delivery time, infrastructure capacity, border-crossing delays, technical interoperability, disruption probability, and security risks. The purpose of this study is to substantiate approaches to optimizing logistics routes between Ukraine and the EU under wartime risks and to identify the factors determining the choice of an efficient, reliable, and resilient route. The methodological framework combines a systems approach, comparative analysis of the principal transport corridors, synthesis of multimodal transport practices, and a multi-criteria approach to logistics decision-making. The study proposes a conceptual objective function incorporating transportation cost, delivery time, risk level, and delay probability, with the weight assigned to each criterion depending on the type, urgency, and value of the cargo. The Polish, Slovak, Hungarian, Romanian, and Danube corridors are examined. The findings indicate that logistics resilience cannot be ensured by a single universally optimal route; instead, it requires a portfolio of interchangeable primary, backup, and supplementary corridors. The principal constraints on route optimization include insufficient capacity at individual border crossings, border queues, incompatibility between the Ukrainian and European railway gauges, limited terminal capacity, and the risk of transport infrastructure disruption or damage. The study substantiates the need to expand multimodal transportation,*

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develop logistics hubs in western Ukraine, extend European-standard railway infrastructure, and strengthen the Danube transport corridor. Digital platforms, GPS and geographic information systems, transport management systems, and artificial intelligence tools are shown to provide a foundation for forecasting delays and dynamically adjusting routes in response to changing operational conditions. The practical significance of the results lies in their potential application by logistics companies and public authorities when designing resilient transport networks, planning alternative corridors, and improving the continuity of Ukraine's foreign trade. The proposed approach links operational efficiency with supply chain resilience and treats route redundancy as an essential component of logistics optimization under wartime uncertainty.

***Keywords**:* route optimization, transport logistics, wartime risks, transport corridors, multimodal transportation, supply chain resilience, logistics digitalization

Данило Грабовський, Дмитро Бугайко. «Оптимізація логістичних маршрутів між Україною та ЄС в умовах воєнних ризиків». *Повномасштабна війна докорінно змінила структуру вантажних потоків між Україною та Європейським Союзом, обмежила використання традиційних морських маршрутів і суттєво підвищила навантаження на автомобільні, залізничні та річкові транспортні коридори. За таких умов вибір логістичного маршруту не може ґрунтуватися виключно на мінімізації відстані або вартості перевезення, оскільки необхідно одночасно враховувати час доставки, пропускну здатність інфраструктури, тривалість проходження кордону, технічну сумісність транспортних систем, імовірність затримок і безпекові ризики. Метою дослідження є обґрунтування підходів до оптимізації логістичних маршрутів між Україною та ЄС в умовах воєнних ризиків і визначення чинників, які впливають на вибір ефективного, надійного та стійкого маршруту. Методологічну основу дослідження становлять системний підхід, порівняльний аналіз основних транспортних коридорів, узагальнення практики мультимодальних перевезень і багатокритеріальний підхід до прийняття логістичних рішень. Запропоновано концептуальну цільову функцію вибору маршруту, яка враховує транспортні витрати, тривалість доставки, рівень ризику та ймовірність затримки, а вагомість кожного критерію визначається видом, терміновістю і цінністю вантажу. Проаналізовано польський, словацький, угорський, румунський і Дунайський коридори та встановлено, що стійкість логістичної системи забезпечується не одним універсально оптимальним маршрутом, а портфелем взаємозамінних основних, резервних і додаткових напрямів. Визначено ключові обмеження маршрутної оптимізації: недостатню пропускну здатність окремих пунктів пропуску, черги на кордоні, відмінність ширини залізничної колії України та ЄС, обмежені можливості терміналів і ризики пошкодження транспортної інфраструктури. Обґрунтовано доцільність розвитку мультимодальних перевезень, логістичних вузлів у західних регіонах України, інфраструктури європейської колії та Дунайського транспортного коридору. Показано, що цифрові платформи, системи GPS і GIS, системи управління транспортом та інструменти штучного інтелекту створюють основу для прогнозування затримок і динамічної зміни маршруту відповідно до поточної ситуації. Практичне значення результатів полягає у можливості їх використання логістичними компаніями й органами державного управління для формування стійких транспортних мереж, планування альтернативних маршрутів і підвищення безперервності зовнішньої торгівлі України.*

Ключові слова: оптимізація маршрутів, транспортна логістика, воєнні ризики, транспортні коридори, мультимодальні перевезення, стійкість ланцюгів постачання, цифровізація логістики.

Introduction. Cooperation between Ukraine and the EU in the transport sector is governed by the Association Agreement between Ukraine and the European Union,

the European Atomic Energy Community, and their member states. The aim is to promote the development of stable transport systems, ensure efficient and safe transportation, as well as intermodality and operational compatibility of transport systems. (Mission Ukraine to European Union (2026)).

In today's environment, logistics is one of the key factors supporting stable international trade and economic development. For Ukraine, the transport and logistics system is particularly important: the country remains an important link in European and international supply chains, while its geographical position creates opportunities for active transport connections with the European Union and other regions of the world (Ministry of Infrastructure of Ukraine (2025), European Commission (2025)). At the same time, the full-scale war has fundamentally changed the conditions in which the transport system operates, forcing both businesses and the state to seek new logistics solutions.

Before 2022, a significant share of Ukrainian exports and imports moved through Black Sea ports. Maritime transport made it possible to ship large volumes of grain, metallurgical products, raw materials, and other cargo at relatively low cost. As a result of hostilities, infrastructure damage, and restrictions on navigation, a substantial share of freight flows had to be redirected to land and river routes.

With maritime transport constrained, part of the load shifted to road and rail crossings with the EU and to the Danube corridor. As a result, Poland, Slovakia, Hungary, and Romania became even more important as transit countries. At the same time, the European Union launched the Solidarity Lanes, a network of alternative corridors that helped maintain the flow of Ukrainian exports and imports.

Under these conditions, the shortest route is far from always being the best one. Transport planning must simultaneously take into account cost, transit time, infrastructure capacity, border conditions, technical limitations, and wartime risks. Route optimization between Ukraine and the EU is therefore not merely an operational task for logistics companies, but an important component of the country's economic resilience.

The purpose of this study is to identify the main approaches to optimizing logistics routes between Ukraine and the European Union under wartime risks and to analyze the factors that influence the choice of an efficient, reliable, and resilient route.

1. Transformation of Ukraine's Logistics System during the War. The full-scale war has placed Ukraine's transport system under severe pressure. Changes in port operations, damage to rail and road infrastructure, risks to warehouse facilities, and general instability have forced established supply chains to be reorganized rapidly.

One of the most visible changes has been the reduced ability to use traditional maritime routes. As a result, Ukraine's land border with EU countries has gained strategic importance, with Poland, Slovakia, Hungary, and Romania becoming key directions for a significant share of Ukrainian exports and imports.

The EU Solidarity Lanes have played an important role in this restructuring. They provided additional road, rail, river, and maritime routes through which Ukraine can export agricultural products, metals, and industrial goods while importing fuel, equipment, humanitarian cargo, and other essential products.

At the same time, shifting a substantial share of freight traffic to land routes created new problems. One of the most important is the limited capacity of certain border crossings. Even when roads and railways within Ukraine operate without major restrictions, cargo may still lose considerable time at the border itself.

For this reason, the efficiency of an international route cannot be assessed solely by the distance between origin and

destination. Actual border-crossing time, road congestion, terminal availability, transshipment options, and the overall condition of infrastructure all have a direct impact on delivery performance.

Another persistent challenge is the difference between Ukrainian and European railway gauges. Ukraine predominantly uses the 1,520 mm gauge, while the standard across most EU countries is 1,435 mm. At the border, this often requires additional operations such as cargo transshipment, changing rolling stock, or applying specialized technical solutions.

Expanding European-standard gauge infrastructure within Ukraine could significantly simplify integration with the EU transport system. In the long term, it could reduce cargo handling time at the border and make rail transport faster and more predictable.

2. Main Ukraine–EU Logistics Corridors. Several key corridors currently shape international freight transport between Ukraine and the European Union.

The Polish corridor remains one of the most important because of Poland's developed transport infrastructure and convenient access to Germany, the Czech Republic, the Baltic states, and other EU markets. It is used extensively by both road and rail transport. Its main advantage is the large number of transport connections and a dense road and railway network. However, heavy pressure on individual border crossings can lead to queues and significantly longer delivery times.

The Slovak corridor through Zakarpattia provides access to Central European markets, including the Czech Republic, Austria, and Germany. It is particularly promising for rail logistics. The development of European-standard gauge sections is gradually reducing the impact of technical incompatibility between the railway systems.

Hungary can serve as an alternative corridor when routes through Poland or Slovakia are congested, temporarily restricted, or economically inefficient. The availability of several interchangeable directions is precisely what makes the logistics system more resilient.

The Romanian corridor is particularly important because it provides access to the Port of Constanța. A multimodal model can be effective here: cargo is transported to Romania by road or rail and then continues by sea.

The Danube transport corridor also occupies a distinct position. River transport can handle significant cargo volumes and connect Ukrainian logistics with European ports. This is especially important for grain and other bulk commodities.

For resilient logistics, Ukraine needs not one supposedly ideal route, but several fully functional corridors. If one direction becomes congested, blocked, or otherwise disrupted, part of the freight flow can then be redirected quickly to another.

3. Factors in Logistics Route Optimization. Under stable conditions, routes are usually compared primarily in terms of price and transit time. During wartime, that is not enough. Reliability must also be included in the calculation: a cheaper and shorter route may prove to be the worse option if the risk of blockage or prolonged delays is high.

Transportation cost remains a basic indicator. It includes not only fuel expenses, but also driver wages, the use of vehicles and infrastructure, loading and unloading operations, and related charges.

Delivery time is equally important. For a business, a delayed shipment may result in production downtime, additional storage costs, missed contractual deadlines, and direct financial losses.

Border waiting time should be calculated separately. On some routes, waiting at a border crossing may be comparable to the actual driving time or even exceed it. Distance alone therefore says little about real delivery speed; data on the actual or average

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processing time at a specific crossing are also required.

Wartime risk should also be treated as a separate variable. This includes possible infrastructure damage, temporary road closures, power disruptions, changes in the operating regime of individual facilities, and other events that are difficult to predict in advance.

Capacity is another constraint. An economically attractive corridor cannot become a full-scale solution for large shipments if its roads, railways, terminals, or border infrastructure are physically unable to handle the required freight volume.

Finally, the availability of a viable alternative matters. If a carrier can switch to another corridor without critical losses, disruption on one route is less likely to paralyze the entire supply chain.

Accordingly, an "optimal route" under wartime conditions represents a compromise among several parameters: cost, time, risk, reliability, and capacity.

In simplified form, the objective function can be expressed as follows:

$$F = w_1C + w_2T + w_3R + w_4D \quad (1)$$

where C is transportation cost, T is delivery time, R is the level of risk, D is the probability of delay, and w_1, w_2, w_3, w_4 are the weighting coefficients assigned to the respective criteria.

The weight of each criterion depends on the type of cargo. For humanitarian aid or urgently needed equipment, time may be decisive. For grain and other bulk commodities, transportation cost may carry more weight. For high-value equipment, safety and reliability become considerably more important.

4. The Role of Multimodal Transportation. One of the most promising directions for the development of Ukrainian logistics is multimodal transportation—the use of several modes of transport within a single supply chain.

For example, cargo may first be transported by truck to a rail terminal, then by rail to a logistics center in the EU, and finally by road for the last leg of the journey. Another option is rail delivery to a Romanian port followed by maritime transport.

The main advantage of this approach is flexibility. The most appropriate mode can be selected for each section of the route, dependence on a single corridor can be reduced, and rail and river transport can be used more efficiently for large cargo volumes.

However, a multimodal model requires appropriate infrastructure: logistics centers, warehouses, transshipment terminals, and digital systems for managing freight flows (Jeej W (2023)).

Coordination between different modes of transport is equally important. If a train arrives at a terminal but trucks for the next stage are not yet available, part of the benefit of a fast route is lost. Optimization should therefore cover the entire chain as a single system rather than treating each section in isolation.

5. Optimization through Digital Technologies. Modern logistics increasingly depends on data. GPS, geographic information systems, transport management systems, and artificial intelligence technologies make it possible to base decisions not only on a pre-defined plan, but also on current conditions Grabovskiy D.Y., Bugayko D.O. (2025)).

A digital platform can simultaneously take into account vehicle location, road conditions, congestion at border crossings, terminal availability, and changes in transportation costs. This creates the basis for dynamic routing.

With this approach, a route does not remain fixed from departure to arrival. If, for example, queues suddenly increase at the planned border crossing, the system can recommend another crossing. The same

principle applies when conditions change on road or rail sections.

Artificial intelligence can add a forecasting layer to this system. By analyzing accumulated data, algorithms can estimate the probability of delays, forecast arrival times, and suggest alternatives in advance (Grabovskiy D.Y., Bugayko D.O. (2025)).

In practice, digitalization changes the very principle of planning: instead of relying on a single route defined at the start, the carrier can adjust it while the shipment is already in transit. During wartime, when conditions on a particular section can change within hours, this flexibility is especially important.

6. Building a Resilient Logistics System. For Ukraine, the task is not simply to restore the pre-war transport system. More importantly, it is necessary to build a model capable of continuing to operate under serious disruption and adapting quickly to new constraints.

One of the basic principles of such a system is route redundancy. For a particular freight flow, for example, the route through Poland may serve as the primary option, Slovakia as the backup, and Hungary or Romania as additional alternatives.

Developing logistics hubs in western Ukraine is another important step. Such hubs can provide storage, sorting, transshipment, and redistribution of goods between different transport modes and routes (Lebedeva, L. , Shkuropadska, D. (2024)).

At the same time, border capacity needs to be increased by modernizing road and rail crossings, expanding terminals, and digitalizing customs procedures. The fewer manual and poorly synchronized operations there are, the more predictable the entire route becomes.

Further integration of Ukraine's railway system with the European network is also strategically important. Expanding 1,435 mm standard-gauge infrastructure could reduce the number of operations required at the border and accelerate freight movement.

It is equally important to continue developing river and port infrastructure in the Danube region. This gives Ukraine additional export options and reduces dependence on individual transport corridors.

Conclusions.

Optimizing Ukraine–EU logistics routes under wartime risks is a complex multi-criteria task. The full-scale war has changed the established structure of Ukraine's foreign trade and significantly increased the importance of land, rail, and river routes.

Today, choosing a route requires more than comparing its cost and duration. Reliability, the risk of delays, infrastructure capacity, security threats, and the ability to switch quickly to an alternative corridor must also be assessed.

Routes through Poland, Slovakia, Hungary, and Romania, together with the Danube corridor, play a key role in connecting Ukraine with the EU market. Developing these directions in parallel makes it possible to diversify freight flows and avoid critical dependence on a single route.

Multimodal transportation remains a promising area of development, combining road, rail, river, and maritime transport within a single supply chain. Digitalization is equally important: GPS, geographic information systems, artificial intelligence, and dynamic routing help operators respond more quickly to changing conditions and make better-informed decisions.

In the long term, the logistics system between Ukraine and the EU should be built around four principles: diversification, multimodality, digitalization, and redundancy. Combining several alternative corridors with modern infrastructure and responsive management enables businesses to adapt to wartime, economic, and infrastructure changes.

Optimization of Ukraine–EU routes therefore goes far beyond simply reducing transportation costs. The quality of these decisions affects the continuity of foreign trade, business operations, the resilience of

international supply chains, and Ukraine's further integration into the European Union's transport network.

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