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**TRANSFORMATION OF GRAIN LOGISTICS IN UKRAINE IN 2022–
2025: ADAPTATION STRATEGIES, THROUGHPUT CAPACITIES
ТРАНСФОРМАЦІЯ ЗЕРНОВОЇ ЛОГІСТИКИ В УКРАЇНІ У 2022–2025
РОКАХ: СТРАТЕГІЇ АДАПТАЦІЇ, ПРОПУСКНА ЗДАТНІСТЬ**

Summary. *The article examines the transformation of Ukraine's grain export logistics in 2022–2025 in the context of full-scale war and the blockade of traditional transport corridors. Based on a summary of scientific works, analytical assessments and factual data, the article characterises key changes in the routing structure: a sharp increase in the role of Danube ports, the redistribution of cargo flows to land crossings with EU countries, the formation of an alternative sea corridor, and an increase in the load on internal infrastructure. An integrated model of the throughput capacity of the new logistics system has been constructed. Key bottlenecks limiting export potential have been identified and the geo-economic consequences for Ukraine and international markets have been formulated. Directions for improving the sustainability of logistics in the military and post-war periods have been proposed.*

Key words: *grain logistics, export, ports.*

Анотація. У статті досліджено трансформацію логістики експорту зернових України у 2022–2025 роках в умовах повномасштабної війни та блокади традиційних транспортних коридорів. На основі узагальнення наукових праць, аналітичних оцінок та фактичних даних охарактеризовано ключові зміни у структурі маршрутизації: різке зростання ролі дунайських портів, перерозподіл вантажопотоків на сухопутні переходи з країнами ЄС, формування альтернативного морського коридору, а також збільшення навантаження на внутрішню інфраструктуру. Побудовано інтегральну модель пропускної спроможності нової логістичної системи. Визначено ключові “вузькі місця”, що обмежують експортний потенціал, та сформульовано геоекономічні наслідки для України й міжнародних ринків. Запропоновано напрями підвищення стійкості логістики у військовий та післявоєнний періоди.

Ключові слова: логістика зернових, експорт, порти.

General description of the problem and its connection with important scientific or practical tasks. The grain sector has traditionally played a key role in Ukraine's foreign trade: in the pre-war period, it accounted for about 40% of export revenues, and Ukraine was consistently among the top five largest exporters of wheat, corn, and barley in the world. Logistics was a critical component of this model, as more than 70% of agricultural exports passed through Black Sea port terminals. Full-scale Russian aggression in 2022 caused unprecedented destruction of transport infrastructure, blockade of most seaports, disruption of logistics chains and a sharp increase in product delivery costs.

The problem is compounded by the fact that during martial law, agricultural exports take on not only economic or fiscal significance, but also geopolitical significance: changes in Ukrainian logistics routes affect global markets, food security in Africa and Asia, and the strategies of international

traders and insurers. That is why research into the transformation of Ukraine's grain logistics in wartime is important not only from an academic point of view, but also for the formation of economic policy, the adaptation of the agricultural sector, and decision-making in the field of international cooperation and investment.

Despite the emergence of new transport corridors — Danube ports, land routes through the EU, and an alternative sea corridor from August 2023 — their capacity, economic efficiency, and sustainability remain insufficiently researched. The scientific problem lies in the lack of a generalised model of logistical adaptation that would allow us to assess how cargo flows have been redistributed, which bottlenecks remain critical, and what geo-economic consequences the change in logistics has for Ukraine and the world.

Analysis of recent studies and publications. Scientific publications from 2022 to 2025 largely focus on describing individual elements of the new logistics system, but there are still few comprehensive studies. The most notable works can be divided into three groups:

- 1) analysis of new export routes,
- 2) research on internal logistics and infrastructure constraints,
- 3) assessment of the international consequences of changes in Ukrainian grain flows.

In his work, Kovalsky thoroughly describes structural changes in export routes, in particular the transition to Danube ports and the growing role of railways. The author provides quantitative estimates of the throughput capacity of Izmail and Reni, which provides a basis for further calculations of Ukraine's logistics capabilities [1].

Mylnychuk focuses on the international dimension, analysing the impact of the war on global grain supply chains. The article examines in detail the work of the Black Sea Grain Initiative, the formation of an alternative maritime corridor, and the response of international traders to increased risks [2].

Bodnar, Halchynska, and Larina propose a marketing approach to analysing changes in grain logistics, emphasising companies' adaptation strategies, diversification of sales channels, and transformation of contract models. Their research highlights the importance of coordination between the state and business during periods of logistical instability [3].

Kurudji develops an optimisation model for selecting logistics routes in conditions of partial blockade. The work has high practical value, as it includes mathematical models for selecting the optimal export direction based on time, risk and cost criteria [4].

Lomotko and co-authors analyse internal infrastructure constraints — elevator capacities, railway stations, queues at borders. The authors show how changes in export geography have led to the overload of certain logistics hubs and propose methods for optimising internal flows [5].

International contributions to research are also important. Yanovska's publication on the ScienceDirect platform assesses the "bottlenecks" of Ukrainian logistics using quantitative models and compares the throughput capacity of land crossings with the needs of the export season [6].

Penkova studies marketing logistics, focusing on changes in trader behaviour and the emergence of new export channels to EU countries [7].

Husenko analyses the risks of maritime logistics and the impact of infrastructure attacks and insurance rates on shipowners' behaviour [8].

Karavayev summarises statistics on changes in the structure of grain exports for 2022–2024 and shows a reorientation towards the Danube cluster [9].

Finally, Nekrasenko's study, conducted before the war, is a key reference point for understanding how logistics has changed: the authors describe the vulnerabilities of Ukrainian logistics, which the war has only exacerbated [10].

Despite the large number of studies, most of them are either descriptive or fragmentary. Insufficient attention has been paid to a comprehensive assessment

of the throughput capacity of new routes, the formation of an integrated model of logistical adaptation, and the study of geo-economic consequences.

Formulation of the article's objectives. The purpose of the article is to conduct a comprehensive study of the transformation of Ukraine's grain export logistics in 2022–2025, including a quantitative assessment of the capacity of new routes, an analysis of infrastructure constraints, and a determination of the geo-economic consequences for Ukraine and international markets.

To achieve this goal, the following tasks have been set:

Analyse structural changes in grain export logistics routes in 2022–2025 based on scientific sources [1–10].

Assess the throughput capacity of Danube ports, land crossings and alternative sea corridors.

Identify the main bottlenecks in the logistics system — transport, infrastructure, and administrative.

To investigate the impact of routing changes on export profitability, trader behaviour and global prices.

Formulate recommendations for strengthening the resilience of Ukrainian logistics in the context of war and post-war recovery.

Presentation of the main research material

The pre-war model of grain logistics as a starting point for analysis

Before the full-scale war began, Ukraine had one of the most concentrated grain export formats in Europe: about 70–75% of the volume came through the Black Sea ports of Odesa, Chornomorsk, Pivdennyi, Mykolaiv, and Kherson. In addition, the Dnipro River was navigable until the Kakhovka Hydroelectric Power Plant dam was blown up. This model ensured low transportation costs and high turnover rates, but at the same time created systemic vulnerabilities, which were described in pre-war studies. In particular, Nekrasenko and his co-authors noted that high dependence on port logistics is a critical risk in the event

of military or political threats, and that internal rail routes have limited flexibility and insufficient capacity for large-scale diversification [10].

Thus, the pre-war logistics structure was economically efficient but strategically vulnerable. This became a decisive factor during the events of 2022.

The logistics shock of 2022: port blockade and initial redistribution of flows

In February–April 2022, Ukraine lost access to most of its seaports, which led to a sharp decline in exports. Already in the first months of the war, grain exports fell more than threefold, and the logistics system was forced to quickly switch to alternative channels that had previously been of a secondary nature. Kovalsky shows that the first attempts at reorientation included maximising the use of rail crossings to Poland, Romania, Hungary and Slovakia, but the capacity of these routes proved to be limited [1].

Mylnychuk emphasises that, at the global level, the sudden disappearance of Ukrainian grain from the market caused prices to rise, and traders were forced to look for new supply routes, which further complicated the logistics landscape [2].

The transition to Danube ports as a key adaptation strategy

One of the most successful adaptation strategies was the use of the Danube cluster — the ports of Izmail, Reni, and Kiliya. Until 2022, their role was minimal: on average, they handled about 5% of grain exports. However, in 2023–2024, the situation changed dramatically: according to Kovalsky's estimates, cargo turnover increased 6–8 times, which effectively turned the cluster into the main export channel [1].

Bodnar and his co-authors describe in detail the mechanisms by which companies adapted to the new conditions: increased investment in transshipment, expansion of the fleet of non-self-propelled barges, a logistics

partnership with Romania, and the use of the port of Constanta as a strategic hub [3].

Another important factor is that the Danube route proved to be more secure in terms of military risks: attacks on the grain infrastructure of the Black Sea coast did not affect the ability of these ports to operate.

Land routes: rail crossings, road corridors and their limitations

Although land routes became critically important at the start of the war, they have natural limitations. Lomotko and colleagues point out that the Ukrainian broad-gauge system is incompatible with the EU gauge, requiring the transshipment of wagons at the border, creating queues and increasing delivery times [5].

The main land crossings — Yagodin, Mostyska, Chop, and Batevo — have been operating at capacity. Yanovska's study on ScienceDirect shows that the actual throughput capacity of most crossings does not exceed 1–1.2 million tonnes per month, while Ukraine's export needs reach 5–6 million tonnes during peak periods [6].

Although flexible, road routes are less cost-effective, as they increase costs by 30–40%. Their role has grown mainly for small farmers and exporters who do not have access to large port infrastructure.

Domestic logistics and infrastructure bottlenecks

The change in export geography has put significant pressure on the domestic logistics network. Lomotko and other researchers point to the following problems [5]:

Overloading of elevators in Western Ukraine, which were not designed for such volumes of production.

An imbalance in the Ukrainian Railways' rolling stock, as the main freight flows have shifted from the Black Sea ports to the border.

An increase in waiting times at certain logistics hubs to 7–12 days.

Rerouting has led to an increase in transport distance of 300–700 km.

These changes have significantly increased the cost of logistics and reduced the profitability of exports, especially for small producers.

Alternative sea corridor: from experiment to stable model

After the Black Sea Grain Initiative ended, Ukraine opened its own "Ukrainian maritime corridor" in August 2023, which runs along the coast and is protected by the Navy. Milnychuk notes that this route has become key to restoring large export volumes, as maritime transport has the lowest cost [2].

Karavayev emphasises in 2024 that the corridor has allowed the return of Panamax-type grain ships, which has dramatically increased transport capacity and created the conditions for a partial return to pre-war logistics parameters [9].

Throughput capacity of new routes: quantitative assessment model

Based on the data provided in sources it is possible to construct a generalised model of logistics throughput capacity. In total, the system can provide:

Danube cluster: 2.5–3 million tonnes per month;

- alternative sea corridor: 3–4 million tonnes per month;
- railway crossings to the EU: 1.2–1.5 million tonnes per month;
- road routes: up to 0.5 million tonnes.

During peak periods, Ukraine is capable of exporting 6.5–7.5 million tonnes of grain products per month, which is close to pre-war levels. However, the system remains vulnerable to attacks, administrative delays and congestion at certain hubs.

Geo-economic consequences of logistics transformation

The change in logistics has significant international implications.

First, the role of Romania and Bulgaria as re-export partners has grown (the port of Constanta has become the largest hub for Ukrainian grain in Europe).

Secondly, the structure of contracts has changed: Penkova notes that some traders have switched from long-term maritime contracts to short-term rail and river agreements [7].

Thirdly, the behaviour of shipowners and insurers has changed. Husenko describes a sharp increase in marine risk insurance rates in the Odessa Gulf area and the impact of this factor on the decisions of international corporations [8].

Overall, the adaptation of Ukrainian logistics has led to the formation of new transport corridors between Ukraine and the EU, which is of long-term importance for the country's integration into the European market and future post-war reconstruction.

Conclusions and prospects for further research. The results of the study give reason to assert that the transformation of Ukraine's grain export logistics in 2022–2025 has become one of the most significant structural changes in the agricultural economy since independence. The loss of access to major seaports and the destruction of critical infrastructure necessitated a rapid restructuring of logistics chains, resulting in the formation of a new multi-level routing system.

First, the study showed that the Danube ports became a key element of logistical adaptation, accounting for up to 40% of total grain exports in 2023–2024. A significant increase in cargo turnover, investments in transshipment expansion, and enhanced cooperation with Romania have created the basis for the relatively stable operation of this cluster in high-risk conditions [1; 3].

Table 1

**Characteristics of the main logistics routes for Ukrainian grain exports
according to scientific sources**

Route	Throughput capacity	Advantages	Limitations/risks
Seaports (Odesa, Chornomorsk, Pivdennyi, Mykolaiv, Kherson)	Up to 75% of pre-war exports	Lowest cost, large-tonnage vessels, stable logistics	Limited capacity of port stations, huge queues of trucks

Route	Throughput capacity	Advantages	Limitations/risks
Ukrainian alternative sea corridor (from August 2023)	3–4 million tonnes/month	Return of large-tonnage fleet, lower cost than land transport	Risks of shelling, dependence on supplies from the Ukrainian Navy
Danube ports (Izmail, Reni, Kiliya)	6–8-fold increase; up to 2.5–3 million tonnes/month	Resistance to blockade, cooperation with Romania, access to the port of Constanta	Overloading, limited depths, lack of barges
Railway crossings to the EU (Yagodin, Mostyska, Chop)	1–1.2 million tonnes/month	Relative security, access to EU ports	Track incompatibility, queues, hub congestion
Road transport	0.3–0.5 million tonnes/month	Flexibility, opportunity for small exporters	High cost, queues, transshipment restrictions

Secondly, land routes through EU countries, despite their functionality, remain limited due to infrastructural and technical factors, primarily track incompatibility, overloaded crossings and insufficient development of border logistics hubs. This is confirmed by studies by Yanovska and Lomotka, which show that the capacity of rail corridors is significantly lower than potential demand during peak export periods [5; 6].

Thirdly, the alternative Ukrainian maritime corridor, which began operating in August 2023, has significantly increased overall logistical stability, allowing the resumption of maritime transport of Panamax-class vessels and reducing transportation costs. Its role in the export structure is growing, as noted in the works of Milnychuk and Karavaev [2; 9].

Fourthly, internal logistics remains one of the key constraints on the development of export potential. Bottlenecks at railway junctions, uneven utilisation of elevator capacities and increased transport distances have a negative impact on the profitability of agricultural production, as confirmed by analytical studies by Lomotka et al. [5].

In addition, the strategic consequences of logistical transformation go far beyond the economy. The change in routes has significantly affected the geo-

economic balance in the Black Sea and Danube regions, strengthening the transport role of Romania, Poland and Bulgaria. This contributes to the deepening of Ukraine's integration into the EU internal market and forms new structures of agricultural cooperation, which is consistent with the conclusions of Penkova and Husenko regarding the international behaviour of traders and shipowners [7; 8].

Prospects for further research include several key areas:

Modelling the resilience of logistics to military risks, including analysis of the impact of attacks on infrastructure and the possibilities for its restoration.

An in-depth assessment of the integration of Ukrainian transport routes into European TEN-T corridors, which is critical in the context of European integration.

Formulation of econometric models of the impact of routing changes on global grain prices, given the high sensitivity of markets.

Analysis of the effectiveness of investments in logistics projects in the Danube cluster and at border crossings.

Research on the role of digital solutions in improving the efficiency of logistics processes, in particular the automation of border queues, cargo movement monitoring and risk management.

In summary, it can be argued that the logistical adaptation of agricultural exports has become one of the key factors in maintaining Ukraine's economic stability during the war. At the same time, the established system requires comprehensive development, investment and further integration into the European transport infrastructure. This determines the relevance of the topic for future scientific and applied research.

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