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Article

Study of the functioning of transport and logistics infrastructure for freight transport in the EU-Ukraine border zone

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Abstract: Global transformational processes associated with the geopolitical fragmentation of the world, changes in supply chains, and the emergence of threats to food, energy, logistics security, etc. have impacted the increase in the freight traffic volumes through the Ukraine-European Union (Ukraine-EU) land border section. In this context, the transport and logistics infrastructure on this section of the border was inadequate for the growing demand for international freight transport, leading to huge economic, social, and environmental damage to all participants in foreign trade. The aim of this paper is to study the efficiency of the functioning of the transport and logistics infrastructure on the Ukraine-EU border section. The taxonomy used in the paper made it possible to look into economic, security, geopolitical, logistics, transport, legal, and political factors shaping the freight traffic volumes, structure, and routes; their key trends and impact on the generation of freight traffic are described. Statistical analysis of freight traffic by border sections and with respect to border crossing points allowed the identification of bottlenecks in the functioning of the transport and logistics infrastructure and outlining ways to address them. The results of the study will be helpful both to researchers working on the issues of freight transport and to policymakers involved in transport and border infrastructure development.

Keywords: transport and logistics infrastructure; throughput capacity; freight transportation; foreign trade relations; automobile border crossing points

1. Introduction

According to the Sustainable Trade Index 2023 (Hinrich Foundation, 2023) in today's ever-changing global economic landscape there is a shift from an era of rapid globalization to what's commonly referred to as "slowbalization" and to one of trade fragmentation and rising protectionism. The World Trade Organization (WTO) has halved its growth forecast for global goods trade, dropping it to 0.8% from 1.7% (World Economic Forum, 2023). Signs of a trade recovery are emerging for 2024, according to global shipping company Maersk (Ward-Glenton, 2023). The war in Ukraine and geopolitical tensions remain the biggest factors impacting international trade thorough 2023–2024 (UNCTAD, 2023).

Despite the war, Ukraine remains one of the world's top agricultural producers. It is a net exporter of these products and a leading supplier of foodstuffs and fertilizers to global markets. Ukraine is among the top five exporters of wheat (9% of world exports), barley (9%), corn (13%), sunflower seeds (2%), and sunflower oil (42%)

(FAO, 2022). Before 2022, about 90% of Ukraine's agricultural products were exported through the Black Sea ports. The blockade of Ukrainian ports and the severance of trade and economic relations with Russia and Belarus have affected freight transport logistics. The processes of increasing the export of food products by land transport with the use of river ports, reorientation to European sales markets, and the adoption of Regulation 2022/870 of 30 May 2022, on the Opening of the European market for goods originating from Ukraine, have increased the intensity of freight traffic through the Ukraine-EU border section significantly. Total trade in goods between the EU and Ukraine reached €57.8 billion in 2022 (European Commission, 2023a). In the years 2018–2022, the trade volume between Ukraine and its neighbors (Poland, Slovakia, Hungary and Romania) has accelerated dramatically by 70%, 27%, 13%, and 230%, respectively. The rapid growth in the rail and road freight traffic volumes in the direction of Poland, Slovakia, Hungary, and Romania increases significantly the load on the transport and logistics infrastructure of the border regions of Ukraine. In this context, the current throughput capacity of the transport and logistics infrastructure is insufficient: vehicles are forced to queue for several days at the border crossing points (BCPs), deliveries are untimely and hard to predict, environmental safety issues are exacerbated due to the lack of organized rest areas for truck drivers, etc.

Border infrastructure should be developed in recognition of future freight traffic volumes, based on an integrated approach to the balanced development of all transport and logistics infrastructure facilities and subject to the requirements of the European Green Deal to increase the use of more sustainable forms of transport, and to improve multimodality to build a sustainable and resilient TEN-T (Trans-European Transport Network) (European Commission, 2023b).

This paper is devoted to the issues of the development of transport and logistics infrastructure in the Ukraine-EU border zone in the conditions of global geopolitical fragmentation and changes in supply chains. The efficiency of infrastructure development was investigated through the analysis of its throughput capacity, as well as through the analysis of economic losses of participants of foreign economic activity. The study analyzes the throughput capacity of the BCPs network on the entire section of the Ukraine-EU border, by separate sections of the Ukraine-EU border and by separate BCPs as well. The problem of the efficiency of functioning of the transport and logistics infrastructure in the EU-Ukraine border zone has been intensified in 2022–2023, and has become globally important. In contrast to other studies conducted in this area, the paper uses a systematic approach to the study of the functioning of transport and logistics infrastructure.

The paper provides a taxonomy of transport demand factors. The qualitative and quantitative analysis of the main influencing factors on the formation of demand for freight transportation made it possible to group them into seven main categories. The paper describes their anticipated trends, and their impact on the formation of demand for freight transportation.

2. Literature review

The development of transport and logistics infrastructure for freight transport is

the subject of many studies in transport geography, international economics, process management, systems analysis, etc. The primary objectives of such studies are to assess the level of development of logistics infrastructure, address the issues of the efficiency of the functioning and development of border infrastructure, and manage them.

To date, the Logistics performance index (LPI) is a benchmarking tool used for assessing the level of development of a country's logistics infrastructure. The Index has been calculated by the World Bank every two years since 2010 and evaluates the ease of arranging shipments and the development of trade logistics at the national and international levels (The Logistics Performance Index, 2023).

The International LPI provides a qualitative evaluation of a country according to six logistics indicators (Customs, Infrastructure, International shipments, Logistics quality and competence, Tracking and tracing, and Timeliness). The 2010-2018 value of the said Index for Ukraine indicates variable trends in the development of the logistics sector in the country. Ukraine showed its greatest progress in 2010-2012, when in two years it rose from position 102 to 66 among 155 countries. In 2023, Ukraine took 79th place among 139 countries, showing significant deterioration in all six logistics indicators.

Infrastructure is also the subject of research when calculating the Global Competitiveness Index (Schwab, 2019). The score is calculated based on the following components: road connectivity, quality of road infrastructure, the efficiency of train services, airport connectivity, the efficiency of air transport services, liner shipping connectivity, and efficiency of seaport services.

To assess the attractiveness of transport corridors, methods are also being developed to assess the attractiveness of routes compared to competitive/alternative routes, find out "real preferences" of transport operators' decision-making on the transport route, develop solutions to improve the attractiveness of the corridor to logistics operators, prioritize actions ensuring the greatest influence on improving the attractiveness of the route, and regularly monitor changes in the route attractiveness index. This method was developed to calculate the Transport Corridor Europe-Caucasus-Asia (TRACECA) transport corridor attractiveness index for road transport (TRACEKA, 2008). For this purpose, the main criteria for route attractiveness are travel cost, time cost, reliability, safety, and security.

A particular aspect of the study of the development of transport and logistics infrastructure is the rationale for opening new BCPs. In particular, the developed methodology for assessing the priority of opening BCPs made it possible to calculate the integral index of promising BCPs in the Zakarpattia Oblast (Prytula et al., 2022). While determining the priority of opening BCPs on the state border, the following factors were taken into account: The complexity of the object; the horizontal and vertical relationships; a low predictability of the object (passenger and freight traffic forecasts); the functional purpose of BCPs, etc.

Based on the analysis of border procedures in the countries of South East Europe, proposals and measures were developed for the improvement of border crossings, which could have direct positive effects on transport and trade in the region. Four groups of indicators have been used for the analysis of BCPs and their performance: indicators of time (the average, maximum and minimum (waiting and procedural)

times required for the completion of all the transactions for imports and exports individually), facilitation (the working conditions of administration staff), procedures (the estimated number of commercial vehicles cleared in less than the threshold of 15 or 30 min; all the steps for passengers and commercial vehicles/ trains since their arrival at the station until their departure, in both directions (entering and exiting the country); the tools (techniques and technologies) used step by step for all the necessary checks and transactions) and effectiveness (the revenue performance and achievement of target collections) (Miltiadou, 2017).

Some researchers analyze congestion in BCPs, terminals, etc. using the queuing theory as a conceptual framework (Motono et al., 2016). The efficiency of their functioning was determined by the gate service time. The aforementioned authors have noted that utilization rate is a useful indicator for forecasting the occurrence and alleviation of congestion. It depends on average trailer arrival rate, average gate service rate, and number of gate lanes. Studies have also revealed that trailers carrying incorrect documentation (IDTs) contribute to landside traffic jams. However, the Hakata port example shows that the Logistics IT system, or "HiTS", can be used to remove IDTs.

Using the model method, Wander and Peirce (2011) predict operating at BCPs and optimize their operations based on infrastructure constraints, traffic lane quantity and type, and current traffic and service patterns. The model validates the advantages of the NEXUS program for travelers (at the Canada-USA border), resulting in lower wait times and operational costs for customs facilities.

Other models have also demonstrated their usefulness in the design of BCPs infrastructure. For instance, computer simulation models were created to design the facilities and infrastructure needed for efficient border and customs inspection operations in a new customs post in Sadao, serving cross-border traffic between Thailand and Malaysia (Opasanon and Kitthamkesorn, 2016). When analyzing infrastructure design, waiting time is employed as a performance metric.

Most studies focus on the analysis of individual components of the logistics and transport infrastructure: BCPs, terminals, roads, etc. Equally, it is important to use an integrated approach in spatial planning for the development of border infrastructure for freight transport.

This paper aims to examine, in light of global changes, the efficiency of the transportation and logistics infrastructure on the Ukraine-EU border section. The following goals were established in order to achieve this purpose:

- To investigate the automobile BCPs' throughput capacity in the transportation and logistics infrastructure system on the EU-Ukraine border section.
- To examine the factors shaping the demand for freight transport along the EU-Ukraine border section.

3. Methodology

The study made use of both quantitative and qualitative data. These include general statistical data from the State Statistics Service of Ukraine and the State Customs Service of Ukraine, as well as indicators for each BCP (roughly 25 indicators). It also took into account findings from surveys that the European Business

Association and the National Bank of Ukraine had undertaken among Ukrainian enterprises.

The level of loading of automobile BCPs in 2022 has been estimated based on data on their design and actual throughput capacity. The paper investigates the throughput capacity of the network of BCPs both as a whole on the entire section of the EU-Ukraine border, as well as in the separate sections of the EU-Ukraine border and at separate BCPs.

The taxonomy was used in order to group the factors influencing the demand for freight transport on the Ukraine-EU border section. According to Greneback (2013), it is helpful for outlining the components and tracking interactions thereof. The authors conducted a systematic quantitative and qualitative analysis of the primary drivers of freight traffic generation on the EU-Ukraine border section, examined current developments in processes indicative of the aforementioned factors and their effects on freight traffic volumes, routes, and modes of transportation. The aforementioned trends were evaluated based on available statistical data, content analysis of academic papers from both inner and foreign sources, comparison of international indices and experience in the development of transportation and logistics infrastructure, statistical analysis of international freight traffic by border sections and in relation to the BCPs.

Graphical analysis was also employed in order to analyze the structure, dynamics, and interrelationships of freight traffic and better visualize the study results. This study also relied on expert opinion.

4. Results

4.1. Evaluation of the automobile BCPs' throughput capacity in the transport and logistics infrastructure system on the EU-Ukraine border section

The logistics of transporting goods through Ukraine's territory were impacted by the closure of this country's ports, the suspension of its airports, the restricted use of its rivers for transportation, and the breakup of its trade and economic ties with Belarus and Russia: In 2022, the share of international transportation by land transport increased by 20% (from 48% in 2021 to 68% in 2022); the intensity of freight traffic across the Ukraine-EU border section increased significantly (in 2022, the number of border crossings by trucks increased by 20.3%, by freight wagons by 21.7%, by freight by 21.3%) (**Figure 1**).

Since 2020, an increase in the number of border crossings by trucks has been observed in most sections of the border. The greatest increase in the load on the border infrastructure was observed on the Ukrainian-Polish and Ukrainian-Romanian sections of the border. The ratio of the increase in the number of trucks crossing the border in 2022 was 13.5:3.5:1:30.4 for the Ukrainian-Polish, Ukrainian-Slovak, Ukrainian-Hungarian, and Ukrainian-Romanian sections of the border, respectively. Concurrently, crossings in the direction "to Ukraine" predominated on all border sections, apart from the Ukrainian-Hungarian one. **Figure 2** shows the dynamics of truck traffic by sections of the EU-Ukraine border during 2018–2022.

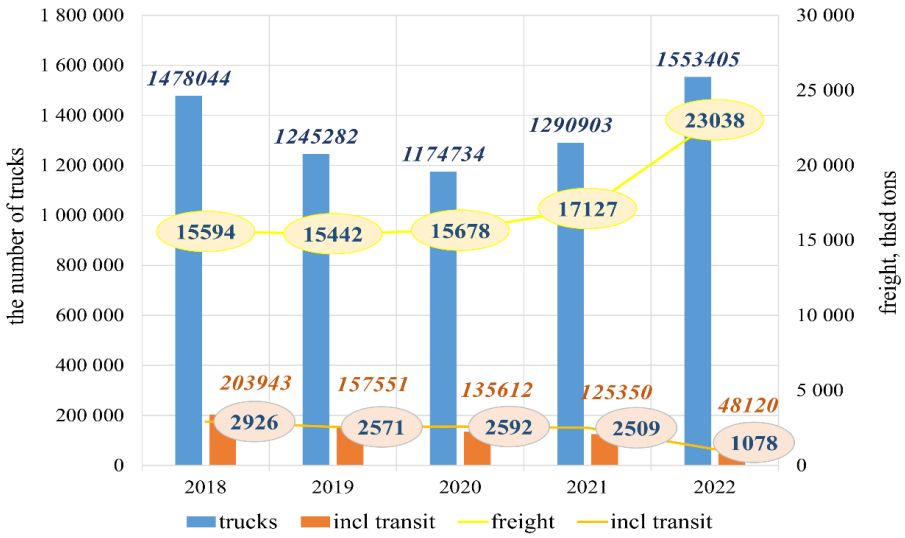

Figure 1. The dynamics of truck border crossings and the volume of goods transported (State Customs Service of Ukraine, 2023).

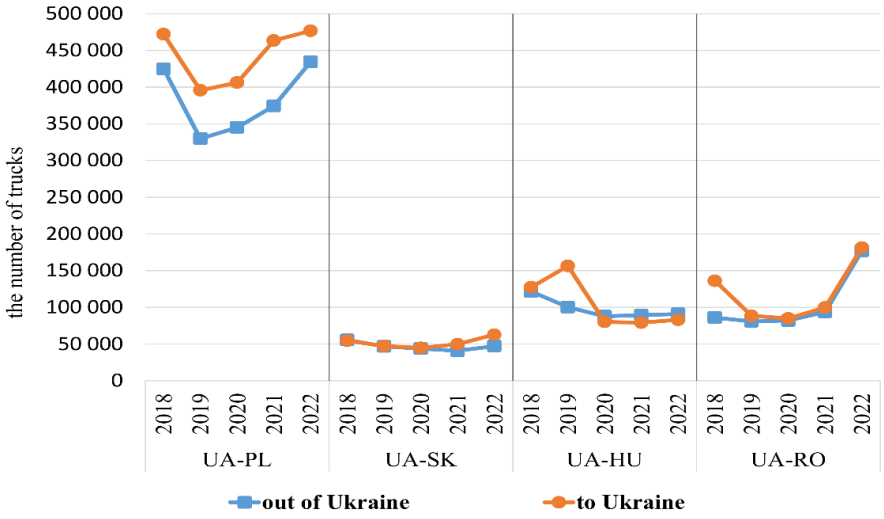

Figure 2. Dynamics of truck traffic by sections of the EU-Ukraine border (State Customs Service of Ukraine, 2023).

In 2022, the number of crossings through the land section of the border increased, but this growth did not correspond to the existing design capacity of BCPs. In particular, on the Ukrainian-Polish section of the border, the actual passage of trucks exceeded the design capacity of BCPs by 41%, and on the border between Ukraine and Romania by 16% (**Figure 3**).

The high intensity of freight traffic, non-uniformity of flows and the insufficient throughput capacity have caused huge queues in front of the BCPs both from the side of Ukraine and from the side of the EU countries. **Figure 4** shows the dynamics of queues during July–December 2022, which were formed in front of the BCPs on the Ukrainian–Polish section of the border in the direction “out of Ukraine”.

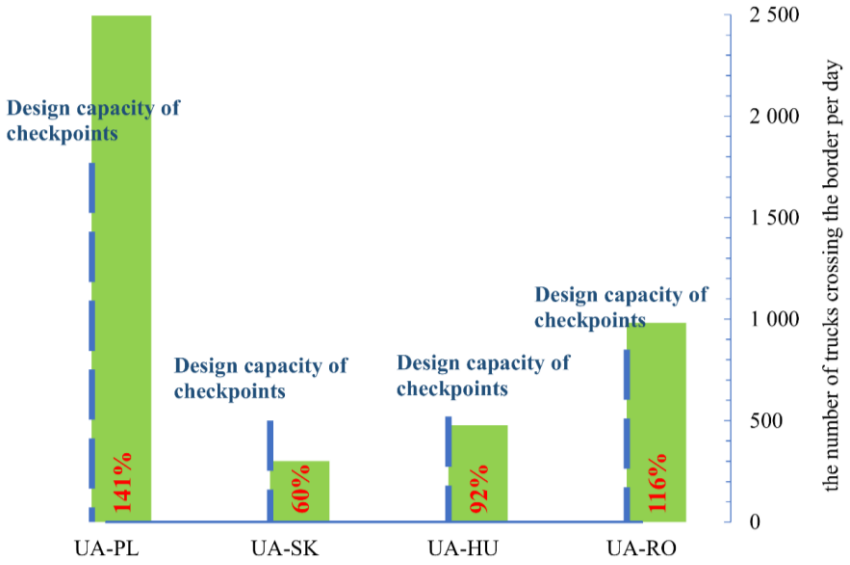

Figure 3. Load level at automobile BCPs by sections of the Ukraine-EU border, 2022 (State Customs Service of Ukraine, 2023).

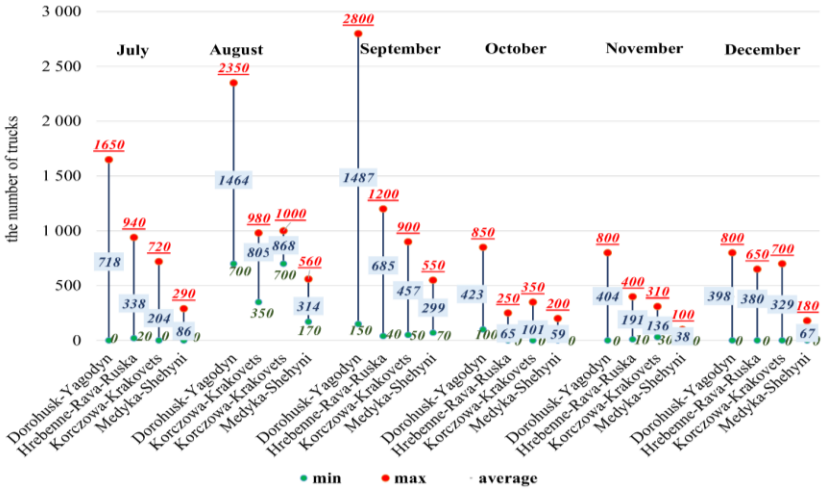

Figure 4. Queues in front of automobile BCPs in the direction "out of Ukraine" on the Ukrainian-Polish section of the border units (State Customs Service of Ukraine, 2023).

Expert estimates state that the carrier's losses for a single day of disruption at the border come to roughly 400 euros (Derkach, 2023). The most critical situation with queues occurred in September 2022 at Dorohusk-Yagodyn BCP, in front of which the queue of trucks from the Ukrainian side stretched for more than 50 km, and at Hrebenne Rava-Ruska BCP for 32 km (Kurnosov, 2022). During this period, the idle time of trucks averaged 10 days. Taking into account only the situation with the passage of trucks at these two BCPs on the Ukrainian-Polish section of the border, the losses for the country's economy amounted to about 8,700,000 euros per month. There are 8 international BCPs on the Ukraine-EU border for the passage of trucks over 7.5 tons, so such losses in 1 month can reach 35 million euros only for carriers.

The issues with the transportation and logistics infrastructure's low throughput capacity in 2022–2024 went beyond technological limitations. In particular, from 6 November 2023, Polish carriers blocked the movement of goods on the border with

Ukraine, later Slovak carriers joined them (Ukrainian Pravda, 2023). According to the calculations of the European Business Association, on average, one day of downtime due to a strike at Polish-Ukrainian BCPs caused one Ukrainian company about UAH 1 million in losses (€25,000) (Forbes Ukraine, 2023).

The National Bank of Ukraine estimates that in November 2023, the blockade of specific land BCPs through Ukraine's western borders resulted in $160 million in export losses and a $700 million drop in imports (Vinokurov, 2023). The closure of the Ukrainian-Polish border in November alone resulted in a 40% drop in exports via BCPs, which cost the Ukrainian state budget UAH 9.3 billion (232.5 million euros) because customs fees were not paid (Pylypiv, 2023).

Therefore, the mismatch of the throughput capacity of the transport and logistics infrastructure for freight transport with the real volume of international freight transport causes huge economic losses to all participants in foreign trade relations, both exporters and importers. In this particular case, on the Ukraine-EU border, the low throughput capacity of the transport and logistics infrastructure leads to an aggravation of the situation not only in the food sector, but also in the spheres of social, energy and logistics security in the global dimension.

4.2. Analysis of the factors shaping the freight transport demand on the Ukraine-EU border section

Analysis of the main factors shaping the freight transport demand allowed to group them into seven categories. Their key trends and their impact on the generation of freight traffic are described (**Table 1**).

Table 1. The main factors that determine the demand for freight transport.

Factors			**Trends**
Economic Factors	Consumption	Demand for products	Growth in demand for the main commodity items of export and import of Ukraine
	Production	Economic activity	In the third quarter of 2023, a trend towards revitalization of the economic activity of industrial enterprises emerged
	Trade	Trade	Export volumes in physical volume are growing
		Trade partners	Increasing the share of EU countries
		Trade routes	Formation of new logistics routes bypassing Russia and Belarus
	Economic geography	Land use	Concentration of transport and logistics infrastructure facilities in the Ukraine-EU border areas
Security Factors	Course of war	High-tech developments	Reduction of security risks
Geopolitical Factors	Trans-European Transport Network (TEN-T), International transport corridors	International transport corridor routes	Reorientation of supply chains
Logistics Factors	Supply Chains	Packaging (container transportation)	Increasing demand for container transportation
		Fragmentation/ regionalization	The change in logistics will shape new routes and infrastructure facilities

Table 1. (*Continued*).

Factors			Trends
Transportation Factors	Automobile transportation	BCPs	Increase in throughput capacity
		High-speed highways (motorways)	Construction of new roads
		Volumes	An increase in the number of crossings
		Terminals	Development of terminals along the border
Legal and Regulatory Factors	EU-Ukraine	-	Reduction of trade and regulatory barriers
Political Factors	EU-Ukraine	-	Blocking of crossing the BCPs

4.2.1. Economic factors

Economic factors are among the key factors that determine the demand for freight transport. By 2050, it is expected that the world's population will grow to nearly 9 billion; thus, increasing our need for food by more than 100 percent (Protect the Harvest, 2023). Global cereal consumption is expected to reach 2813 million tonnes in 2023–2024, up 2.4 million tonnes from the previous month and 1.1% more than in 2022–2023 (FAO, 2023). According to Fitch Ratings, the industrial recovery in developed markets—where manufacturing largely lagged headline growth in 2023—and sustained stimulus in China will drive base metal demand growth in 2024 (Fitch Ratings, 2023).

The top ten exported goods continue to include corn, sunflower oil, iron ores and concentrates, wheat, sunflower seeds, etc. They account for more than 50% of export revenue and more than 70% of the physical volume of exports. TOP-10 export and import commodity groups as of 2022 are shown in **Table 2**.

Table 2. TOP-10 export and import commodity groups, 2022.

Export		Import	
Maize	13.45%	Oil and oil products	14.77%
Sunflower, safflower or cottonseed oils	12.37%	Oil gases	10.45%
Ores and iron concentrates	6.59%	Passenger cars and other motor vehicles intended primarily for the transportation of people	4.95%
Wheat	6.06%	Other goods	3.91%
Rape seeds	3.49%	Medicinal products are dosed or packaged for retail sale	2.61%
Insulated wires, cables and other insulated electrical conductors; fiber optic cables	3.01%	Coal stone, anthracite	1.98%
Sunflower seeds	2.84%	Electrical telephone or telegraph devices; video phones	1.71%
Carbon steel semi-finished products	2.7%	Insecticides, rodenticides, fungicides, herbicides, disinfectants	1.53%
Flat rolled carbon steel 600 mm wide or more, hot-rolled, unplated, without galvanic or other coating	2.28%	Tractors, other than tractors of heading 8709	1.34%
Soya beans	1.95%	Power generating units and rotating electrical converters	1.16%
The share in the value equivalent	54.74%	The share in the value equivalent	44.40%
The share in physical equivalent	75.78%	The share in physical equivalent	59.61%

Source: Calculated based on the data of the State Customs Service of Ukraine (2023).

Despite all the military risks and logistical difficulties, Ukraine remains an

important supplier of iron ore. The EU countries have become the key market for Ukrainian exporters instead of China. In January–April 2023, Ukrainian iron ore exports to the EU amounted to 19.7% of the total European imports. Ukraine has the largest reserves of iron ore needed for steel production and a great potential in green energy, which will be the main source for hydrogen production (GMK, 2023).

The real GDP of Ukraine in 2022 fell by 29.1%. The decline in real GDP was the deepest in the history of Ukraine, its value dropped to the level of the early 2000s. After a long decline in the level of economic activity starting in 2022, in August–September 2023, the index of industrial production of Ukraine (before the corresponding period last year) amounted to 101.2% and 102.4%, respectively (National Bank of Ukraine, 2023). The revitalization of the economic activity of industrial enterprises will affect the formation of demand for both domestic and international freight transport.

In 2022, in the conditions of a full-scale war against Russia, the drop in the volume of foreign trade of Ukraine by 27% was primarily the result of a drop in the volume of exports by 35% (primarily due to the blockade of sea ports and active military operations in the east and south of the country). In 2023, compared to 2022, export volumes increased by 112,000 tons and amounted to almost 100 million tons of goods. In terms of monetary value, the indicator fell by 18.7% or $35.8 billion.

EU countries dominate foreign trade with Ukraine. Their share is constantly increasing: from 40.81% in 2019 to 53.35% in 2022 (from 2021, Great Britain belongs to the group of countries “other European countries”) (**Figure 5**).

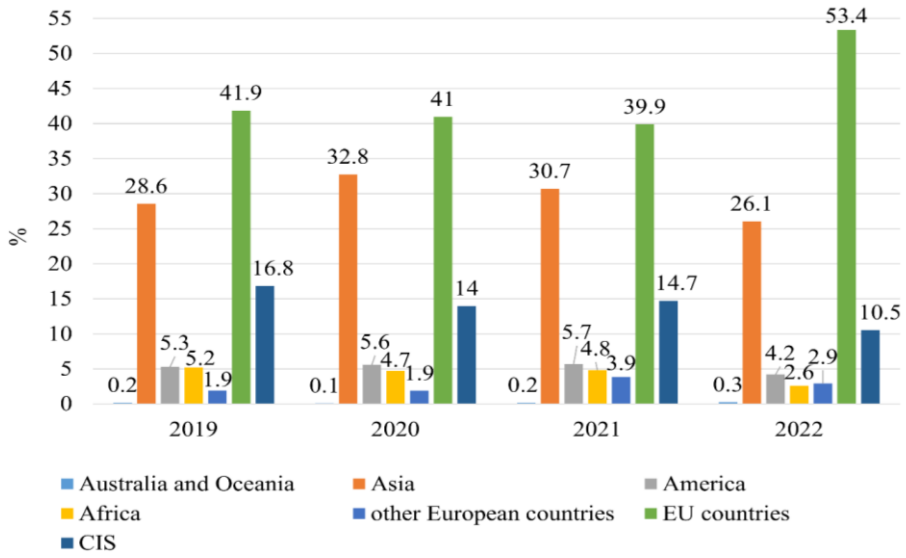

Figure 5. Geographical structure of Ukraine’s foreign trade (State Customs Service of Ukraine, 2023).

The trade volume with some countries has increased significantly as a result of the reorientation towards European markets. For example, in 2022, trade with Bulgaria increased 2.5 times to 3.5 billion dollars, mostly due to food exports. On the list of Ukraine’s top ten trading partners are five of its neighbors. Poland emerged as Ukraine’s principal trading partner in 2022, making up 12% of the country’s total international trade. The volume of trade between Ukraine and all of its neighbors

increased (**Figure 6**).

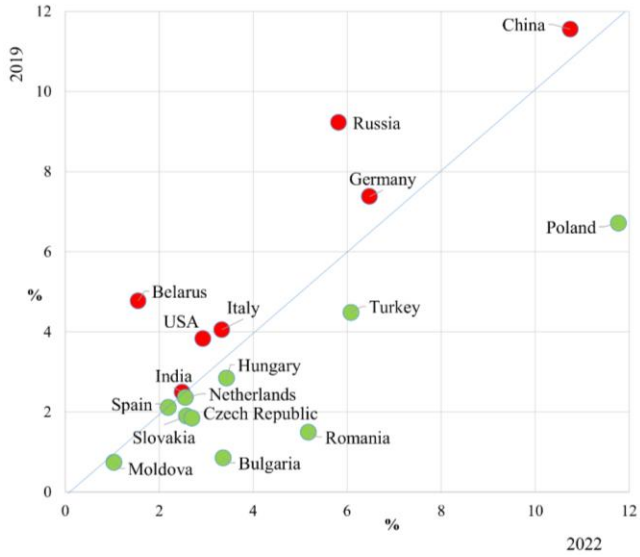

Figure 6. The share of Ukraine's main trade partners in 2019 and 2022, % (State Customs Service of Ukraine, 2023).

Countries whose share has increased in the total volume of trade with Ukraine are marked with green marks; with red marks countries whose share in the total volume of trade with Ukraine decreased. During 2019–2022, the volumes and share of foreign trade of neighboring countries with Ukraine demonstrate high growth dynamics.

The reorientation of export-import logistics routes in the direction of EU countries determines the need for the construction of new transport and logistics infrastructure facilities.

4.2.2. Security factors

On February 24, 2022, the Russian Federation launched a full-scale armed invasion of Ukraine, which resulted in the temporary occupation of a portion of its territory, major damage to natural ecosystems and infrastructure, millions of forced migrants, and a record decline in the country's economy. There was substantial damage to the transportation infrastructure. According to preliminary estimates, a total of 25,400 km of roads and 344 bridges and overpasses were destroyed as a result of hostilities; 507 km of railway track were damaged; 126 damaged railway stations and stations (The Ministry for Communities, Territories and Infrastructure Development of Ukraine, 2023).

The forecasted decrease in security risks and post-war reconstruction are the main reasons for the anticipated 4–6% acceleration in economic growth in 2024 and 2025. But the negative GDP gap will persist over the entire forecast horizon due to the weakening of competitiveness during the war and the long-term preservation of war-induced structural disparities in the markets of goods and services, labor and capital, which will inhibit the recovery of aggregate demand (National Bank of Ukraine, 2023).

4.2.3. Geopolitical factors

The geography, structure and logistics of world trade have undergone significant changes and continue to transform in the face of today's challenges. Reshaping of the

global supply chains bypassing Russia and Belarus affected the launching of new routes of the International Transport Corridors (ITCs). One of the few alternatives to transit traffic along the main route of the New Silk Road (a multimodal route between Europe and China), which passes through the Russia, is now the Middle Corridor (via Kazakhstan, Azerbaijan and Georgia). On 31 March 2022, Georgia, Azerbaijan, Turkey and Kazakhstan signed a quadrilateral statement on the development of the "Trans-Caspian International Transport Route", aimed at strengthening cooperation and increasing the transit potential of the countries along the corridor (Yakovlev, 2022).

In 2022, the EU extended four European Transport Corridors to Ukraine and the Republic of Moldova. Also, the proposal removes Russia and Belarus from the TEN-T maps (The European Union law, 2022). Ukrainian logistics routes are becoming more and more integrated into the ITCs on the important trade route Europe-Caucasus-Asia.

4.2.4. Logistic factors

The development of intermodal and container terminals will contribute to increasing the development potential of the transport and logistics infrastructure by increasing its throughput capacity, expanding the geography of transportation, expanding the list of transport and logistics services, developing all types of transport, attracting investment resources, etc. In EU countries, the share of transportation in containers reaches 45%. However, in Ukraine, unlike the developed countries of the world, their share in the total volume of railway transport remains extremely low − 0.5 to 2.3%. In the context of the reorientation of global logistics supply chains along the new route of the Great Silk Road and the developed transport network, the country has significant potential for the development of a network of intermodal terminals.

In 2023, Ukraine increased exports by container transportation +86% by rail transport and +36% by road (Zharykova, 2024).

4.2.5. Transport factors

In Ukraine, as in most EU countries, road transport has remained the leader in the volume of transported goods for the past 10 years. It accounts for more than 75% of all transportation. In the first half of 2023, a positive trend was observed in all sections of the Ukraine-EU border in terms of the number of BCPs crossings by trucks (**Figure 7**).

The highest dynamics of crossings was observed on the Ukrainian-Romanian and Ukrainian-Polish sections of the border. The number of crossings on them increased by 82.9% and 38.8%, respectively. **Figure 8** shows the dynamics of crossings at individual BCPs in the first half of 2023 compared to the same period in 2021.

Compared to the first half of 2021, 239,171 more trucks (a 38.6% increase) crossed the border in the first half of 2023. With increasing freight traffic, the queues redistribute mainly among the largest BCPs: In particular, 28% of 239,171 trucks crossed the border at the Siret–Porubne BCP, 21.4% at Dorohusk–Yagodyn, 12.35% at Medyka–Shehyni, 9.63% at Isaccea–Orlivka. Therefore, first of all, it is necessary to develop the throughput capacity of the border infrastructure around these BCPs.

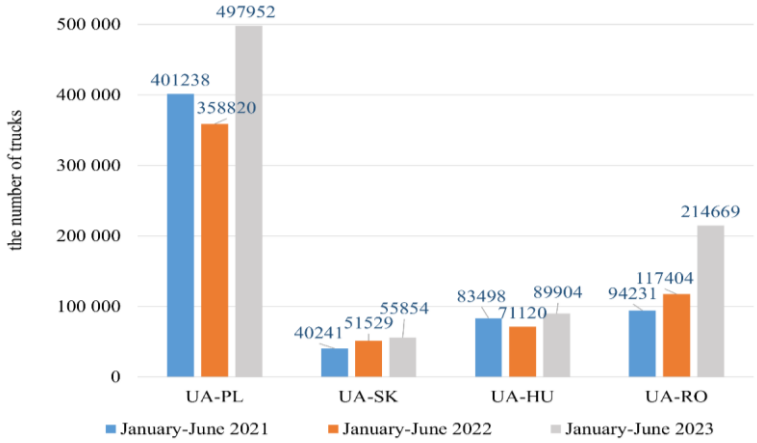

Figure 7. Dynamics of truck traffic by sections of the Ukraine-EU border, January–June 2021–2023 (State Customs Service of Ukraine, 2023).

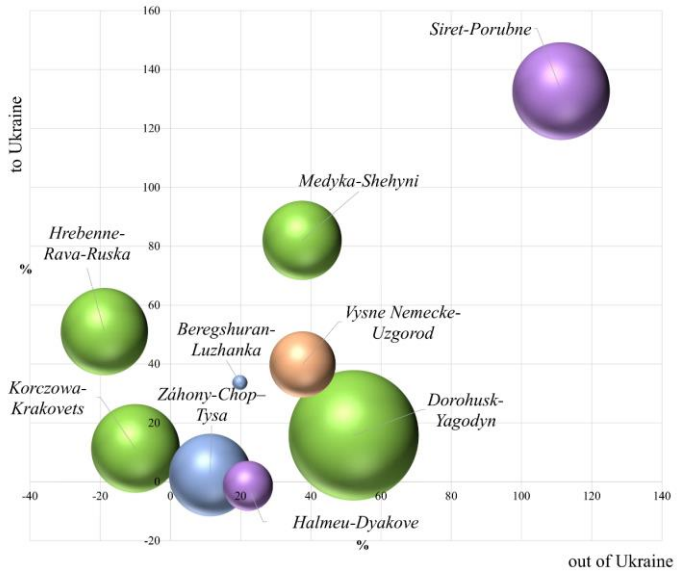

Figure 8. Increase (decrease) in the number of border crossings by trucks, in the first half of 2023 compared to the first half of 2021 (State Customs Service of Ukraine, 2023).

Bubble size represents the share of the BCP in the total number of trucks passed across the border: (a) green bubbles: BCPs on the Ukrainian-Polish section of the border; (b) pink bubble: BCPs on the Ukrainian-Slovak section of the border; (c) blue bubbles: BCPs on the Ukrainian-Hungarian section of the border; (d) purple bubbles: BCPs on the Ukrainian-Romanian section of the border. The number of trucks passing through the BCP Isaccea-Orlivka in the direction "out from Ukraine" has increased threefold and almost doubled "to Ukraine".

COVID-19 affected the decrease in the volume of freight transport in 2019. At the same time, starting with 2020, there is an upward trend in almost all BCPs regarding the number of truck crossings and the volume of transported goods (**Table 3**).

The positive dynamics of crossing the BCPs by trucks is also observed in the first half of 2023 (**Table 4**).

In 2022–2023, the largest queues were observed in front of BCPs on the Ukrainian-Polish (Dorohusk–Yagodyn), Ukrainian-Romanian (Siret–Porubne, Isaccea–Orlivka) and Ukrainian-Slovak (Záhony–Chop (Tysa)) sections of the border.

Table 3. Dynamics of crossing the BCPs in terms of trucks and freight, 2018–2022 (The State Customs Service of Ukraine, 2023).

		Vehicles (trucks)					**Freight, thousand tons**				
		2018	**2019**	**2020**	**2021**	**2022**	**2018**	**2019**	**2020**	**2021**	**2022**
UA-PL	Dorohusk-Yagodyn	302,479	330,159	326,681	348,263	356,334	4068.7	4070.7	3754.5	3819.6	5112.9
	Hrebenne-Rava-Ruska	181,755	147,415	143,012	179,786	202,117	1815	1935	1760	2302	2964
	Korczowa-Krakovets	210,154	173,589	210,138	200,645	217,082	2565	2835	3245	3225	3480
	Medyka-Shehyni	180,647	73,983	71,535	107,885	131,018	613	698	671	1191	1587
UA-SK	Vysne Nemecke-Uzgorod	110,118	94,039	88,386	90,774	109,940	1605.9	1245	1266.3	1260.7	1987.8
UA-HU	Záhony-Chop–Tysa	240,382	252,096	164,963	163,329	167,409	2230.9	2000.3	2363.3	2334.9	2256.8
UA-RO	Halmeu-Dyakove	59,458	53,435	51,813	57,425	63,832	904.3	840.5	813.4	832.1	878.9
	Siret-Porubne	162,724	115,755	115,089	112,168	227,910	1789.4	1805.2	1799.6	1777.4	3716.1
	Isaccea-Orlivka	-	-	-	24,005	60,341	-	-	-	371	1010

Table 4. Dynamics of crossings the BCPs in terms of trucks and freight, the first half of 2021–2023 (The State Customs Service of Ukraine, 2023).

		Vehicles (trucks)			**Freight, thousand tons**		
		H1 2021	**H1 2022**	**H1 2023**	**H1 2021**	**H1 2022**	**H1 2023**
UA-PL	Dorohusk-Yagodyn	165,586	132,296	216,677	1961.3	1649.4	3298.7
	Hrebenne-Rava-Ruska	86,996	85,585	97,314	1120	1198	1514
	Korczowa-Krakovets	98,068	88,590	100,207	1597	1398	1694
	Medyka-Shehyni	50,570	51,324	80,097	525	585	1114
UA-SK	Vysne Nemecke-Uzgorod	40,241	51,529	55,854	586.3	1189.2	732.1
UA-HU	Záhony-Chop–Tysa	81,198	68,396	87,006	1125	897.7	1203.3
UA-RO	Halmeu-Dyakove	29,019	22,700	32,075	447.1	314.8	464.1
	Siret-Porubne	54,869	72,132	121,875	857.6	1178.6	2377.7
	Isaccea-Orlivka	-	-	-	165	320	618

Transport communications continues to be one of the things preventing Ukraine's transport and logistics infrastructure from reaching its full development potential. The length of expressways in the country remains extremely small, the technical condition of the road and transport network is unsatisfactory. Ukraine lags far behind the EU countries in terms of road density and the share of expressways. The low throughput capacity of transport networks is a restraining factor in increasing the volume of freight transport along the Ukraine-EU border. 10 out of 12 BCPs for freight transport on the Ukrainian side are adjacent to a road of international importance, 8 of which are part of European routes. The category index of these roads is extremely low. Today, the A4 highway adjoins the Korczowa–Krakovets BCP only from the Polish side.

Current throughput capacity of transshipment terminals and warehouses operating today is extremely low. This especially applies to container terminals. Regionally, the largest number of container terminals operate in the Odesa region. Three container terminals have been created on the territory of Kyiv region, and 2 terminals each in Dnipropetrovsk, Lviv and Kharkiv regions.

4.2.6. Legal and regulatory factors

In 2022, three visa-free regimes were adopted, which directly affected the volume of freight transport on the Ukraine-EU border section:

- Regulation (EU) 2022/870 of the European Parliament and of the Council of 30 May 2022 on temporary trade-liberalisation measures supplementing trade concessions applicable to Ukrainian products under the Association Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part, and Ukraine, of the other part (extended to June 2024)— "economic visa-free regime".
- Agreement between the European union and Ukraine on the carriage of freight by road (Special Agreement on the Liberalization of Road Transport), 29 June 2022 (has been extended until 30 June 2024)— "transport visa-free regime".
- Application of Common Transit Convention and the Convention on the Simplification of Formalities in Trade in Goods (the international application of NCTS) (from 1 October 2022)—"customs visa-free regime".

4.2.7. Political factors

Political factors are no less important in shaping the demand for freight transport. On 23 June, the leaders of 27 EU member states granted Ukraine the status of a candidate for EU membership. Therefore, the integration of the Ukrainian economy into the European economic space will only gain momentum and will be accompanied by an increase in foreign trade volumes. Blocking the operation of BCPs on the Ukraine-EU border section by carries and farmers (November 2023 until now) is a response to the Ukrainian export growth to the EU markets and its competitiveness. It should be emphasized that in wartime the efficient development of transport and logistics infrastructure in the EU-Ukraine border is also a matter of survival.

5. Discussion

In 2022–2023, the transport and logistics infrastructure at the Ukraine-EU border has proved unable to meet the growing demand for freight transportation on this section of the border. The latest study of the Logistics Performance Index showed a serious drop in Ukraine's ranking to 79th place among 139 countries, showing a significant deterioration in all six logistics indicators (The Logistics Performance Index, 2023). This situation led to the emergence of huge queues in front of international BCPs both in the directions "to Ukraine" and "out of Ukraine". In particular, in September 2022 alone, losses for carriers from the Ukrainian side amounted to about 35 million euros. The main reasons for queues were high intensity of freight traffic, non-uniformity of flows and the insufficient throughput capacity.

The problem of low throughput capacity of border infrastructure is a complex problem, as it concerns the throughput capacity of transport networks, BCPs, other objects of transport and logistics infrastructure (terminals, logistics centers, warehouses, service areas, etc.). In the case of our study, BCPs turned out to be the most bottleneck. Similar studies regarding the problems of queue formation and reduction of waiting time were conducted by Wander and Peirce (2011), Motono et al. (2016), Miltiadou (2017). They studied queues at BCPs and terminals from the standpoint of optimizing services at border crossings and cargo handling in terminals.

At the same time, the problem of the formation of queues at the EU-Ukraine border is more extensive, which cannot be solved only by the implementation of certain innovative and technological solutions at the stage of crossing the border. Solving the problem also requires the development of physical infrastructure (expansion of existing BCPs and/or opening of new BCPs, construction of expressways, opening of new terminals, etc.). This, accordingly, requires significant capital investments in the long term. Planning the development of transport and logistics infrastructure should be coordinated by Ukraine and, first of all, by the EU countries. The implementation of such large-scale infrastructural projects has been complicated by the security situation in Ukraine and the priority of the country's defense expenditures.

6. Conclusion

The reorientation of the main international freight traffic towards the western border of Ukraine has increased the load on the border infrastructure (**Figure 1**). In 2022, the increase in the number of truck crossings through the Ukraine-EU land border section exceeded the current design throughput capacity of the BCPs. In particular, the actual throughput of trucks on the Ukraine-Poland border section exceeded the design throughput capacity of the BCPs by 41%, and on the Ukraine-Romania border section by 16% (**Figure 3**). This factor to a large extent contributed to huge queues at the border. According to the Queuing Theory (Kleinrock, 1975), in real conditions, system failure (a high probability of exponential queue growth) is observed when the capacity utilization rate of service systems reaches 0.8–0.9 of design indicators. Heavy and uneven traffic and insufficient throughput capacity impacted the formation of queues.

During 2022–2023, the largest queues of trucks were observed at BCPs at the Ukraine-Poland border section (**Figure 4**), where the total number of border crossings by trucks exceeded the number of border crossings through the other three sections of the Ukraine-EU border (**Figure 2**). The introduction of the eCherha system (The online queue management system for border crossings by international freight transport has been launched at the end of 2022) that was intended to address the factor of uneven traffic did not solve the issue with queues. At the end of 2022, queues continued to form at almost all BCPs, being especially long at the Siret–Porubne, Záhony–Chop (Tysa), and Isaccea–Orlivka BCPs. With increasing freight traffic, the queues redistribute mainly among the largest BCPs. Low throughput capacity at BCPs results in significant economic loss.

It was identified that economic, security, geopolitical, logistics, transport, legal, and political factors shape the freight traffic volumes, structure, and routes (**Table 1**). Economic factors are among the key factors shaping the further upward dynamics of freight traffic at the Ukraine-EU border section. International rating agencies forecast further growth in demand for foodstuffs and metals, which account for more than 70% of Ukraine's physical exports (**Table 2**). An upward trend in foreign trade, an increase in the share of EU countries from 40.81% in 2019 to 53.35% in 2022, and the development of new trade routes bypassing Russia and Belarus bring about well-defined growth prospects for freight traffic volumes. The said factors would be amplified by geopolitical factors through the approval of new maps of international

transport corridors and TEN-T and the formation of plans for the development of transport and logistics infrastructure along the border with the EU. On July 27, 2022, The European Commission (COM (2022) 384 final) has officially approved the revision of the maps of the TEN-T, expanding them to include routes in Ukraine. A number of road and railway routes are included in four of the nine main European transport corridors. In September 2023, the European Commissioner for Transport, Adina Valean, announced that Ukraine and Moldova will be able to apply for financing of infrastructure projects to the Connecting Europe Facility (CEF) on the same terms as EU member states. Attracting funds from EU funds will contribute to improving the efficiency of border infrastructure.

The growth in container transport demand will reorient part of traffic to rail transport. This, however, would not affect significantly the growth prospects for freight traffic in the context of strengthening processes of Ukraine's integration into the EU through the adoption of a number of visa-free (economic, transport, and transit) policies.

The blockade of BCPs by the EU countries has emerged as a serious challenge for Ukraine's economy. Leveling the negative effect of political factors is the primary mission of European and Ukrainian politicians. According to the forecast of the National Bank of Ukraine, the country's economic growth rate is expected to accelerate to 4–6% in 2024 and 2025, primarily under the forecast's assumption concerning reduced security risks. Security factors can amplify or weaken the effect of other factors on the shaping of the freight transport demand.

The paper is mostly focused on the analysis of quantitative parameters of infrastructure functioning, rather than, for example, the quality and offer of services provided during freight transportation. The limitations of the study are also the incompleteness of the information. Some data is closed for use.

To summarize, in the context of post-war reconstruction and the intensification of international trade geared towards Ukraine's rebuilding needs, the volume of foreign economic transactions will keep growing. This will also require adequate development of transport and logistics infrastructure under increased pressure on existing international automobile BCPs for freight transport.

Future studies will be related to the prospects for the development of multimodal transport in the context of European integration processes.

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