Approaches to modeling the transport logistics
of grain export in wartime conditions

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During its 32 years of existence as an independent state, Ukraine has been and remains a key player in the global food market. It provides sustenance for approximately 600 million people annually. Ukraine ranks in the top 10 producers and exporters of cereals and oilseeds, as well as products of animal origin (meat and dairy production)[1].

In the 2020-2021 season, poor harvests in many regions of the world due to droughts, floods, and hurricanes were offset by a record harvest in Ukraine (specifically 108.8 million tons of oilseeds and cereals)[2] and several other regions. Alongside this, there arose a greater necessity to enhance and increase logistics to meet the demands of exporting these crops. On February 24th, a turning point occurred in the history of Ukraine, as the country underwent a radical transformation due to becoming the target of full-scale aggression. The systematic cessation of air transportation and maritime shipping gave rise to significant challenges, and substantial delays in rail and road transport emerged as a result of a transportation collapse. Observations of the chaos in the transportation system underscore the necessity for radical changes in logistics. The reorientation of primary logistical flows, particularly towards humanitarian cargoes, became imperative to ensure survival and meet the needs of the civilian population, the military, and the entire country. This has prompted the development and optimization of transport logistics strategies, which have now become one of the key sectors responsible for meeting the nation's needs in crisis conditions..

As of February 2022, 95 % of exports were conducted via maritime routes. From the end of February to July 2022, all ports were blocked, except for the small Danube ports whose capacity was insufficient for pre-war export volumes. Over 20 million tons of cereals and oilseeds were halted for loading in the ports of the Black and Azov Seas. Grain exports in the initial months of the conflict decreased to 500,000 tons per month compared to the usual volume of 5 million tons before the war. According to the Ministry of Agriculture, Ukraine was losing $170 million daily due to blocked ports[2]. The situation improved with the opening of the grain corridor, providing the opportunity to increase the export volumes of grain and other goods.

The second main logistics problem is the limitation of land routes, namely:
- Low capacity of railway stations at the border between countries;
- Different track gauges between the European Union countries and Ukraine;
- Limited access to exports due to grain certification;
- Shortage of drivers for international transportation.

In 2023, a new problem emerged - the closure of borders for Ukrainian grain by neighboring countries. The precondition for the embargo was the low cost of Ukrainian agricultural products, which led to active purchases by grain traders on the European market. Therefore, the Eurocommittee decided to impose restrictions to protect the agricultural sector of neighboring countries. Currently, the Ukrainian government is working individually with each country to resolve the issue of overland exports to third countries worldwide.

Another issue that Ukraine faced was the expiration of the grain corridor agreement, leading to the temporary halt of loading/unloading at the ports of «Great Odessa.» Currently, the Ukrainian government is also addressing this matter by establishing a temporary corridor that accommodates both barges and vessels transporting metals and other types of goods. Additionally, authorities are working with global insurance companies on cargo insurance, partially funded by the insurance companies themselves and partly by state funds.

Therefore, considering the Incoterms CFR (Cost and Freight) - meaning that the seller is obligated to pay for the delivery and load the goods onto the transport, as well as pay the ship's freight charges according to the terms provided by the carrier; make payments for customs services, and in the case of goods intended for export - cover the relevant duties; cover the costs of delivering

the goods to the destination port)[3], the state establishes secure conditions for the final stage of delivery from port to port. The responsibility for delivery to the port (or the CPT Incoterms option) is entirely assumed by the logistics company.

The cost of logistics in hryvnia equivalent has increased by 2-3 times due to the rise in railway tariffs, an extension of the delivery route, an increase in the cost of grain transportation by trucks due to fuel prices, and inflation. Therefore, the main tasks facing logistics companies are the prompt establishment/change of transport routes to ensure driver and cargo safety, as well as optimizing the cost component.

Modeling the transport logistics of grain exports is an important process for optimizing the efficiency of transporting grain crops from farms to ports or other end destinations (such as multimodal terminals), taking into account all relevant factors.

The first step in modeling the transport logistics of grain exports is determining the sources of grain and their storage locations. Subsequently, it is necessary to examine the available transportation routes and choose the most efficient paths that would avoid conflict zones and potential attack areas.

For analysis, let's consider the route «Grain Storage» to «Port» for October 2023 and the corresponding period of the previous year (fig.1).

Transportation date	Average loading time, hours	Average unloading time, hours	Average transportation time, hours	Average distance with cargo, km	Average unloading weight, t
Oct'23	9,75	36,29	52,00	165	23,00
Oct'22	3,27	11,90	32,50	145	24,50

Average transportation time, hours

32,5 (38,46%)

52 (61,54%)

Transportation date
● Oct'23
● Oct'22

Average distance with cargo, km

145 (46,77%)

165 (53,23%)
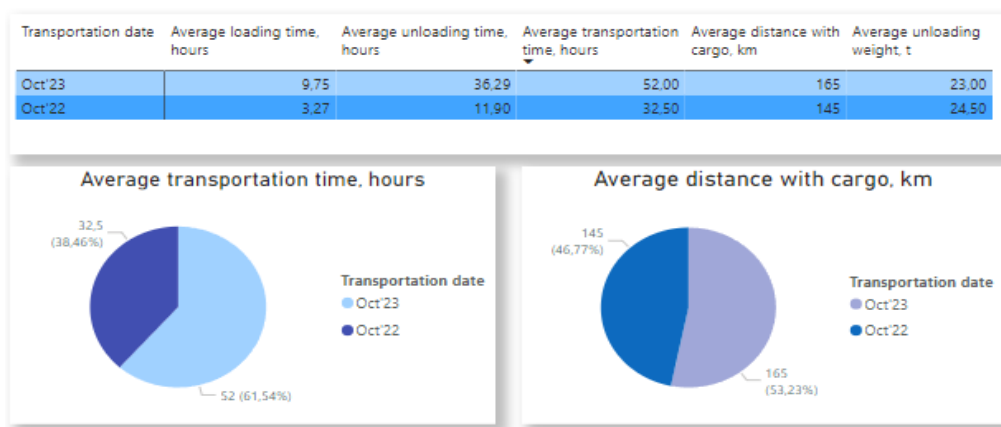
Transportation date
● Oct'23
● Oct'22

Figure 1 – Comparison of «Grain storage» – «Port» transportation for October 2022-2023

From the infographic, it can be concluded that on the selected route in October, the average travel time per trip increased by 60 %. This is due to a threefold increase in the average loading and unloading time. Additionally, there is an increased average distance traveled with cargo by 13.7 %.

Taking into account the number of active ports and their capacity, one can conclude that the most significant factor affecting the travel time during the 2022 period was the smooth operation of the grain corridor. The ports in Odessa worked 24/7, resulting in an average unloading time of half a day. This year, we observe a situation where the primary support for the export process comes from the Danube Delta ports, which have loads many times greater than their capacity. Hence, queues form, and unloading times increase. It is also important to consider that the ports handle a very small number of grain trucks and operate within a limited number of hours per day. This is due to the constant threats from drones and missiles faced by these operational ports.

Considering the data and delving into the issues, the next step in modeling is selecting the most appropriate model according to the set task. For modeling transport logistics, several models can be considered along different directions:

- Mathematical models: Linear programming: Used to optimize the allocation of resources such as vehicles, costs, routes, etc. Goal programming: Allows determining optimal strategies based on defined goals and constraints.
- Agent-based models: Consider the interaction of various agents (vehicles, warehouses, authorities) to determine optimal strategies.
- System dynamics models: Used to understand the probable impacts of changes in the system over time. They can be useful for predicting dynamics in wartime conditions.
- Geographic Information Systems (GIS): Used for analyzing geographical aspects such as optimal routes, geographic constraints, and security.

- Simulation models: Used to simulate various scenarios in a virtual environment, allowing testing strategies and responses to changes.
- Integrated logistics models: Combine different aspects of logistics, including transportation, storage, processing, etc., to create a comprehensive map of the logistics process.
- Simulation models: Used to create simulation models of individual elements of the system to study their interaction and impact on overall logistics.
- Stochastic programming models: Consider uncertainty and probability in choosing strategies, which can be useful in wartime conditions where situations may be unpredictable.

Choosing modeling approaches, it's important to consider the specific characteristics of the logistics chain and the peculiarities of shelling and delays in the export region. Combining multiple models and methods can be useful for gaining a deep understanding of the situation and making more effective decisions.

Transport logistics currently plays one of the most crucial roles in the economy and the functioning of the state. It ensures the supply of food to both relatively safe and frontline territories, delivers weapons and other essential items for the military, and facilitates the export of grain and other goods, providing the opportunity to sell products and support the economy during wartime. Therefore, it is necessary to analyze and actively develop alternative routes, considering all factors influencing delivery costs, crew safety, and cargo security, while minimizing expenses and risks.

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