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Introduction of bimodal technologies for transportation of grain cargoes

V. Malashkin[1], M. Berezovyi[2], R. Korobiova[3]

[1] *Ukrainian State University of Science and Technologies, Ac. Lazaryana St., 2, 49010, Dnipro, Ukraine, E-mail: v.v.malashkin@ust.edu.ua*
[2] *Ukrainian State University of Science and Technologies, Ac. Lazaryana St., 2, 49010, Dnipro, Ukraine, E-mail: m.i.berezovyi@ust.edu.ua*
[3] *Ukrainian State University of Science and Technologies, Ac. Lazaryana St., 2, 49010, Dnipro, Ukraine, E-mail: r.g.korobyova@ust.edu.ua*

Abstract

The purpose of the study is to evaluate the effectiveness of bimodal grain cargo transportation in containers in comparison with other methods of their delivery to seaports. The studying of the grain transportation process is carried out using the methods of mathematical statistics, computer simulation and the theory of organization of railway operational work. Estimation of variants of transportation organization was carried out using the methods of economic-mathematical modeling. The originality of the work is that it received the dependence of the cost of grain cargo delivery on the distance, taking into account the design features of rolling stock and the specific functioning of railway stations for its processing. The practical significance of the work lies in the fact that the implementation of its results allows reducing the logistics costs of grain cargo transportation.

KEY WORDS: *railway transport, grain transportation, bimodal technologies, unit train*

1. Introduction

The grain sector of Ukraine is of great importance for the country's economy. It determines the volume and price of basic food products for the population; it is a source of income for agricultural producers; it affects the development of rural areas. The grain industry is the basis for the sustainable development of many other branches of the agro-industrial complex, and a significant source of agricultural exports. At the same time, the competitiveness of Ukrainian grain on foreign markets depends not only on the quality of work of the country's agro-industrial complex, but also on the ability of its transport system to ensure the delivery of grain to international markets with the lowest costs. This issue has become especially important in wartime, when the elements of the grain storage and transportation system are blocked and are under threat of destruction. In this regard, the introduction of new grain transportation technologies, aimed at increasing resistance to military influences and reducing logistics costs, is an urgent scientific and applied problem for the economy of Ukraine.

2. Literature review and purpose of the study

One of the areas of economic growth of Ukraine is the grain production increase with its subsequent sale on international markets. The main purpose of production of additional volumes of grain is export. At the same time, the internal consumption of grain in Ukraine remains constant, and the export volume of grain crops from Ukraine has a stable upward trend (see Fig. 1). Traditionally, the export of Ukrainian grain is carried out by sea transport. Thus, in 2020, 96.2% of grain was exported through ports, 2.9% through land border crossings by rail and 0.9% by road. However, with the beginning of the Russian aggression, the work of seaports was blocked, which caused a redistribution of export volumes between different transport modes. Thus, for the period from March 2022 to May 2023, the grain export volume through ports amounted to 72%, and through land crossings of the European Union by rail and road transport, respectively, 19% and 9%. It should be noted that Ukraine and the European Union export similar amounts of grain. Because of this, both the storage system and the transport system of the European Union faced significant problems. At the same time, the development of the storage system and the throughput capacity of the transport infrastructure of the European Union for the export of Ukrainian grain is not expedient, since after the end of the hostilities, the cargo flows are reoriented back to the Black Sea ports.

Fig. 1. Grain export dynamics from Ukraine

The main method of increasing the transportation efficiency of grain cargoes in the world in general and in Ukraine in particular is transportation routing. Today, technical routing is mainly used in Ukraine [1]. During the implementation of this technology, the railway forms a route of empty grain cars at one of the technical stations serving grain loading sections. Further, these cars are delivered to the intermediate stations of the section by pick-up and export trains. After the loading, the cars are assembled by the same trains on the technical station to the technical route, which runs to be unloaded at the port without processing on the way. The advantage of this technology is the proximity of railway stations to the farms, which makes it possible to minimize the mileage of cars to deliver grain to elevators for transshipment to railway transport. This also allows reducing the railway expenditures for sorting the cars on the route. The disadvantages are the need to maintain a network of small elevators, the difficulty of organizing grain quality control on them, the need to use shunting diesel locomotives to service intermediate stations, as well as significant downtime of cars at the technical stations for accumulation, that is, waiting for the concentration of a full-fledged route. The similar technology was widely used on North American railways in the USA and Canada until the 80s of the 20th century. But, at the end of the last century, this technology was improved due to enlargement of grain shipments, which led to the emergence of unit train technology [2]. Since the 1990s, the shuttle train technology [3, 4] has been introduced in the USA, which involves loading trains with grain without uncoupling the train locomotives. However, it is necessary to note the significant differences between the working conditions of Ukrainian railways on the one hand and those of the USA and Canada on the other. This is primarily due to the geographical size of the states, which exceed the size of Ukraine by 16.3 and 16.5 times, respectively. Disadvantages of the shuttle train technology compared to the traditional technology of grain transportation are an increase in the distance of grain transportation to the elevators and longer time of grain storage at the elevators. In the conditions when the average distance of grain transportation to ports in Ukraine is about 550 km [5], and significant volumes of grain production are concentrated in proximity to the sea coast, as a result of the increase in the mileage of cars from farms to elevators, direct transportation routes by motor vehicle to ports will be more effective for the part of the dispatchers. During hostilities, elevators are an easy target for missiles and drones, so the concentration of large masses of grain of great value in one place is dangerous.

An alternative to grain transportation in hopper cars is transportation in containers [6]. The main advantages of it include the possibility of sending small cargo batches directly by producers; the possibility of working with direct buyers and small grain traders; the possibility of exporting non-mass grain crops (millet, rapeseed, peas, mustard, etc.); higher cost of grain in the case of dispatching one variety; no need for elevators on the route.

It should be noted that grain transportation is characterized by significant seasonal unevenness of transportation, which leads to downtime of specialized rolling stock during the work volumes decrease. At the same time, containerization is associated with the use of universal rolling stock, which can be used for other purposes during the period of falling transportation volumes. It should also be noted that, in contrast to the capacities for storage and loading of bulk cargoes, significant capacities for container cargoes have been created in European ports. Today, the European Union mainly receives loaded containers and sends the empty ones [7], therefore the reverse loading of containers with Ukrainian grain creates conditions for reducing the cost of goods for European consumers.

In order to reduce the costs of cargo-handling operations, loading and the road network when transporting containers to the USA, bimodal technologies are actively developing [8], which show their competitiveness at distances of 200-500 km, and their use makes it possible to reduce the cost of transportation by 10-15%.

Therefore, the purpose of the scientific work is research and analysis of the implementation effectiveness of bimodal technologies for export transportation of grain cargoes.

3. Solution methodology

Containerization of grain cargo transportation is a technology that is developing in modern conditions. At the same time, wheat, rapeseed, peas, millet, sunflower, and sorghum are mostly transported in containers. Today, about 3% of

grain is exported from Ukraine in containers, but there is a tendency to increase it.

This article considers the option of delivering a grain container by road to a bimodal terminal and its subsequent shipment to the port by rail, as well as alternative options for transporting containers by road to seaports directly from their storage locations. It also considers grain transportation by road to linear granaries, reloading in hopper cars and their subsequent delivery to the port.

It should be noted that in the world, several different bimodal technologies for cargo transportation are used. The RailRunner technology [9] was considered in this study. This technology is based on the use of specialized road tyre-pneumatic trailers with a reinforced frame to absorb longitudinal loads, as well as intermediate and end bogies for moving along the railway. The making- and breaking- up the trains is carried using tractor-trucks, as shown in Fig. 2.

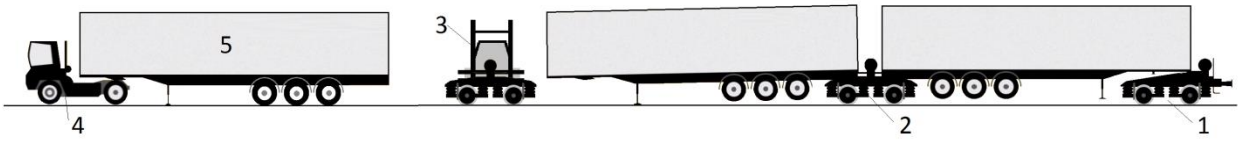

Fig. 2. Formation of a bimodal train.
1 – end bogie, 2 – intermediate bogie, 3 – loader with intermediate bogie, 4 – tractor-truck, 5 –platform with container

The terminal for the formation of bimodal trains is a platform with a hard surface and a rail track laid on the same level for supplying and removing trains, and insulated rail track for bogies. Capital investments for the construction of a bimodal terminal amount to about 10% of the cost of building a container terminal. At the same time, due to the low capital charges, the payback of the terminals is achieved in 1–2 years, and due to the lack of complex equipment, they are not an economically justified target for air attacks.

4. Research results

The advantage of bimodal technology compared to the transportation of grain by hopper car routes is the reduction of costs associated with the performance of initial and final railway transportation operations. Herewith, first, the use of bimodal technology during the routing of grain cargo transportation makes it possible to abandon the creation of a network of elevators that provide mass loading of cars. Second, the use of bimodal technology makes it possible to divide idle time in the port of grain containers, bogies, as well as bimodal platforms, which makes it possible to organize the movement of bogies and platforms by route trains according to the schedule. Compared to transportation by road, firstly, bimodal technology is characterized by lower energy consumption for movement, and secondly, border and customs procedures are simplified.

To determine the area of effective use of bimodal vehicles for the transportation of grain, it was calculated the cost of grain delivery to ports using various technologies. In general, the economic costs associated with the delivery of 1 ton of grain to port terminals can be defined as

$$S = S_{tr} + S_{el} + S_{is}$$

where S_{tr} – are the costs associated with grain transportation by various transport modes;

S_{el} – are the costs associated with grain processing at elevators;

S_{is} – reduced costs associated with the development of infrastructure and rolling stock for transportation.

When performing calculations, it is assumed that the total transportation distance $L_{tr} = L_{rw} + L_{rd}$ (here L_{rw} is the distance of transportation by rail transport, L_{rd} is the distance of transportation by road transport) differs insignificantly for different technologies.

When using bimodal transportation technology, the cost of grain delivery to the port can be determined by the following formula

$$S_{bm} = \frac{S_{rd}(L_{rd}) + S_{bmt} + S_{rwl}(L_{rw}) + \alpha \cdot S_{rwe}(L_{rw}) + S_{bg} \cdot \theta_{bg}(L_{rw}) + S_{fc} \cdot \theta_{fc}(L_{rw} + L_{rd}) + S_c \cdot \theta_c(L_{rw} + L_{rd}) + S_{tc}}{k \cdot q_c} \quad (1)$$

where $S_{rd}(L_{rd})$ – are the costs associated with the delivery of an empty container from the bimodal terminal to the place of loading and the loaded container back;

S_{bmt} – is the rate for bimodal terminal services;

$S_{rwl}(L_{rw})$, $S_{rwe}(L_{rw})$ – are accordingly the costs of transporting a platform with a loaded and an empty container by rail, UAH/pl-day;

S_{bg}, S_{fc}, S_c – are accordingly the rates of payment for using the bogies and platform, as well as the container, UAH per day;

$\theta_{bg}(L_{rw})$, $\theta_{fc}(L_{rw} + L_{rd})$ – are respectively the use duration of bogies and platform, day;

$\theta_c(L_{rw} + L_{rd})$ – is the duration of the container use, days;

α – is the coefficient characterizing the payment share by the grain dispatcher for the return journey of the container during transportation by rail;

S_{tc} – are the expenses related to the container transshipment in the port, UAH;
k – is the utilization rate of the container's carrying capacity;
q_c – is the cargo capacity of the container, t.

The costs associated with grain transportation by road transport include components dependent on and independent of the transportation distance. The costs that do not depend on the transportation distance are associated with obtaining various certificates, as well as additional payments charged by carriers when dispatching grain to ports. In general, the costs of road transportation per 1 ton of grain can be approximated by a non-linear dependence:

$$S_{rt} = \frac{a}{q_v} + \left(b + \frac{1}{c + d \cdot L_{tr}}\right)\frac{L_{tr}}{q_v} + S_t \qquad (2)$$

where a, b, c, d – are empirical coefficients;
l_{tr} – transportation distance, km;
q_v – vehicle carrying capacity, t;
S_t – grain transshipment cost in the port, UAH/t.

The railway transportations costs are related to the operation of railway transport infrastructure and rolling stock, additional fees and charges levied by railways, the costs of grain delivery to elevators by road transport and its transshipment to railway transport, as well as the payment of various certificates. The amount of costs is significantly influenced by grain cars belonging to the fleet of railway-owned cars or to the fleet of own (rented) cars.

When using own (rented) hopper cars, the cost of grain delivery to ports can be determined by the following formula

$$S_{rw}^{rent} = S_{ct}(L_{rd}) + S_{el} + S_t + \frac{S_{tar}^{l}(L_{rw}) + S_{tar}^{e}(L_{rw}) + S_{hc} \cdot \theta_{car}(L_{rw}) + S_{add}}{q_{car}} \qquad (3)$$

where $S_{ct}(L_{rd})$ – is the cost of cargo transporting to the elevator by road, UAH/ton;
S_{el} – the costs associated with grain reloading at the elevator, UAH/ton;
$S_{tar}^{l}(L_{rw})$, $S_{tar}^{e}(L_{rw})$ – the costs related to payment according to the railway tariff for the use of the infrastructure, respectively, during transportation of a loaded or empty car;
S_{hc} – rate for the car use, UAH/car-day;
$\theta_{car}(L_{rw})$ – car turnover, day;
S_{add} – additional costs related to fees charged by railways, as well as obtaining various certificates, UAH/car;
q_{car} – car carrying capacity, t.

The components of the cost elements in expressions (1)-(3) are determined based on simulation modeling of the transportation process using the model [10].

The dependence of delivery cost for 1 ton of grain to the port on the transportation distance for each type of transport is given in Fig. 3.

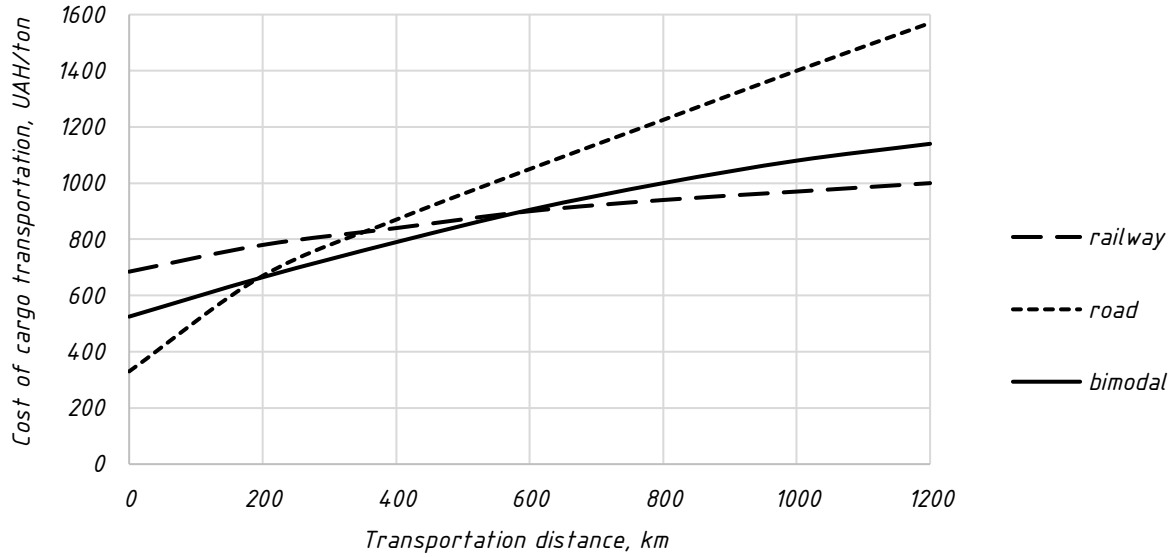

Fig. 4. Transportation cost of 1 ton of grain by various transport modes

Analysis of the obtained results shows that bimodal transportation technologies can be competitive at distances from 200 to 570 km.

On the whole, the originality of the work is that it received the dependence of the cost of grain cargo delivery on a distance taking into account the design features of rolling stock and the specific functioning of railway stations for its processing. The practical significance of the work lies in the fact that the implementation of its results allows reducing

the logistics costs of grain cargoes transportation.

5. Conclusions

The theoretical studies performed in the work make it possible to draw the following conclusions.

1. Grain transportation in containers makes it possible to send small batches of cargo, to store grain without elevators, to create conditions for the work of small grain traders with direct buyers; to export non-mass grain crops, etc. An additional advantage for the conditions of Ukraine is that it is possible to use the existing capacity reserves of container terminals as an alternative to the insufficient capacity of port elevators for grain export when applying such technology.

2. The use of bimodal technology for grain transportation allows reducing the costs of initial and final operations in comparison with railway transport and the operation of movement in comparison with road transport. Due to this, bimodal technology is competitive at distances of 200-570 km.

3. Bimodal technology of grain transportation in containers makes it possible to create a grain transportation system that does not involve significant capital investments in separate elements of the transport infrastructure and the concentration of grain in one place. Due to this, such a transport system is, firstly, resistant to air attacks during martial law, and secondly, it can be reformatted according to the direction of cargo flows without significant losses after the end of the war in Ukraine.

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