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Management of the grain supply chain during the conflict period: case study Ukraine

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Abstract: The paper highlights the main aspects of designing safety supply chains for grain cargoes and other agricultural commodity delivery. The study's relevance is caused by the fact that periodic port blockades do not allow Ukraine to carry out reliable exports of agricultural products along classical routes. Therefore, there was a need to find new alternatives for exporting agricultural commodities, primarily grain. The study aims to substantiate, describe, structure, and mathematically formalize proposed delivery options and choose the best. The research justifies picking supply chains using automobile and railway transport from Ukraine to the European Union countries. According to three proposed technologies, grain cargoes are exported in batches using containers. The advisability is justified for using each considered delivery option regarding technological aspects. Mathematical modeling, particularly regression analysis, is used to design supply chains. In this case, selecting the best technology is confirmed by corresponding calculations according to designed regression models. The presented option for supplying agricultural commodities is the safest and most reliable but more expensive. However, such logistics will be an excellent solution to reduce the negative consequences of a possible food crisis for the global economy.

1 Introduction

The proposed national transport strategy of Ukraine significantly determines the priority areas for achieving quality transport services during the military conflict. This conception also provides for approaching levels of their support and development of transport infrastructure to advanced European standards. During a period of significant uncertainty in transport support, resolving problems is reducing influences of random factors by building intelligent transport systems. It is demonstrated using smart methods (fuzzy patterns) when predicting trip and delivery time [1].

It is also crucial to improve the level of delivery safety and reduce the negative impact of transport on the environment [2]. It is necessary to respond to funds that improve management systems, implement certain administrative reforms, and qualitatively decentralize tasks and functions for central departments relating to local executive power. It will make it possible to design a high-quality technology for supplying grain cargo in containers by Ukraine-Europe routes. A good example is supply chain structures using E-commerce platforms [3]. Digitalization during product or cargo flow control allows manufacturers and transport companies to have a certain level of information support in production and distribution systems. This aspect is particularly important if risks are considered posed by emergencies [4]. Herewith, considered emergencies could worsen the stability of designed food supply chains [5] without enough information support.

In addition to ensuring physical security, an important aspect is the creation of safe financial and economic settlements. It is achieved by using innovative technologies for the traceability of grain delivery quality [6] and using non-standard business criteria for assessing investments in a blockchain-based management information system [7]. Reducing uncertainty factors makes it possible to design a reasonably reliable supply chain [8,9]. It is extremely important in connection with the latest trends.

European partners increasingly note the negative impacts of the current conflict on supply reliability and the food independence of European countries [10]. Experts note a significant price increase and logistics complexity during future distribution [11,12]. Repeatedly, food safety issues were considered at sessions of relevant UN committees. It is evidenced by the adopted resolutions and councils [13]. World Bank representatives [14] and traders selling agricultural products to other world regions are concerned about the situation with supplies from Ukraine [15]. Violating Ukraine's established trade routes with the Asian region also causes some nervousness in the population of Vietnam and other Asian states [16].

All of the above confirms the relevance of presented studies to designing reliable and safe food supply chains in such difficult conditions worldwide.

Ukraine belongs to the leading world producers and exporters of agricultural products, which include sunflower oil, wheat, and barley. Significant nomenclature refers to cereals. However, the Russian invasion suspended perspective transportation routes – through Ukrainian ports on the Black Sea, which processed more than 90% of these exports. The sale of grain is significant for our country because it brings in nearly twenty percent of Ukrainian export earnings. In addition, Ukrainian cereals provide food safety for numerous countries in Europe, Asia, and Africa. The European Commission (EC) has developed and implemented measures to assist in transporting various commodities from Ukraine to make grain cargo export safer [17].

The EC quite qualitatively assessed problem areas in supply chains. Thousands of rail wagons with grain have been detained from the Ukrainian part near frontiers with such countries as Poland and Romania. The average idle time at the border is nearly 16 days, sometimes a month [18]. The main problem at the same time is the width difference in tracks between the railways of Ukraine and European countries. Therefore, to move across state borders, specialists must either change "bogies with wheels" on railway wagons or transshipment cargoes from Ukrainian vehicles to European ones. However, existing capabilities are not enough with current transportation demands, according to data of EC.

Therefore, European officials turned to companies with a proposal to allocate or find "mobile grain reloaders" on the market. One option is also proposed - to deliver grain cargo directly in universal containers since they can be reloaded faster with appropriate cranes from the railway platforms belonging Ukrainian railway to the European one [19].

Since the beginning of the 2021–2022 marketing year (from July 2021), Ukraine has increased the corresponding volumes of export supplies for grain cargo by more than 30% – to 42.6 million tons [20]. Corn and wheat were the most exported. According to official statistics, Ukraine sold 32.5 million tons of grain abroad (Figure 1) in the 2013–2014 marketing period. In 2017–2018, export sales decreased to 39.4 million tons. But the country sold 50.4 million tons of grain to foreign markets in the next quarter, and 2019-2020 – 57.2 million tons. Export deliveries amounted to 44.9 million tons last time. In particular, Ukraine exported 23.1 million tons of the main grain cargo – corn, 16.6 million tons of wheat, 4.2 million tons of barley, and 18.4 thousand tons of rye. As of February 21, 42.6 million tons of grain cargoes were exported in the 2021–2022 marketing period: more corn - 18.7 million tons, wheat – 17.8 million tons, barley – 5.6 million tons, rye – 160.1 thousand tons [21].

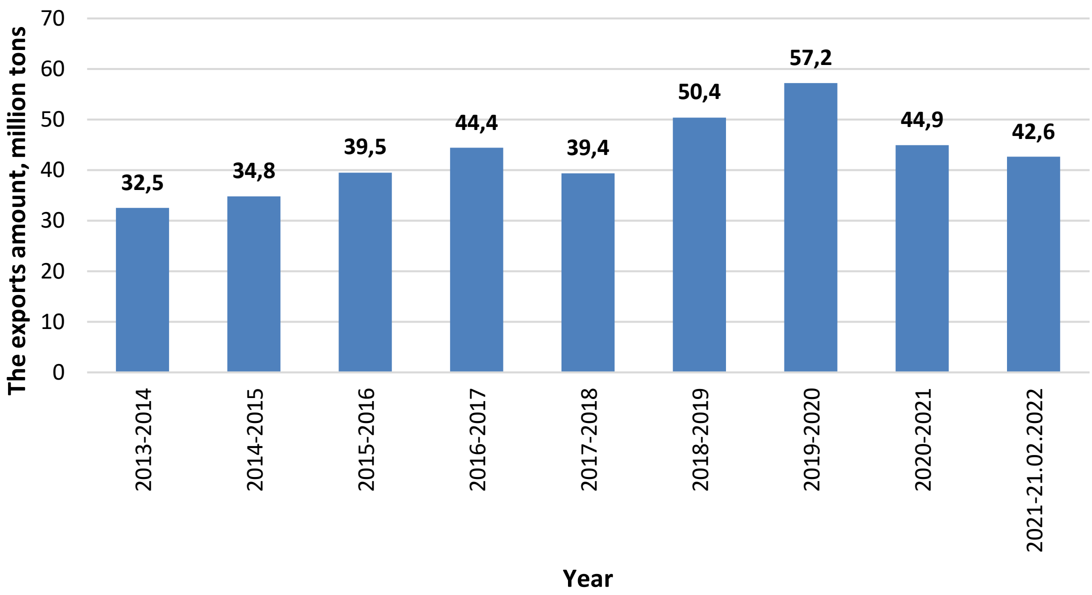

Figure 1 The exports amount of grain and leguminous, and products of their processing in 2013-2021

The grain cargo supply to Europe is a complex technological process where it is necessary to develop multimodal clusters in which production, warehouse, and transshipment capacities will be combined. In the current situation in Ukraine, supply chains using containers for goods delivery are more efficient and reliable but relatively costly. It should make it possible to simplify the process of boundary crossing for railway transportation, precisely with insignificant volumes of orders by rail, but with a considerable distance – for example, when delivered to the Poland or Spain ports [22]. And this aspect is also providing a rational interaction between all elements of supply systems with minimal resource costs. Therefore, it is necessary to choose a methodological approach for designing rational technology grain cargo supplied in containers by Ukraine–Europe routes.

The export of agricultural products from Ukraine is a strategic industry. At the same time, a significant share of products transported by leading international carriers [23] are oilseeds, cereals, and beans. Ukraine exports 91.2% of grain cargo by sea; the rest is by automobile and railway transport. The difficulties associated with changes in the geography of shipments force carriers to look for new, effective solutions. One of these is grain delivered in containers. This transportation kind is characterized by universality, which allows carriers to supply products in small batches with a volume of 500 to 5000 thousand tons. Container transportation allows transport companies to establish contact details with small consumers due to the constant regularity of container international lines, a certain delivery period, and abilities to plan processes clearly.

Grain crops are delivered in bulk by universal containers. This transportation type is characterized by the following advantages: reasonable cost of corresponding freights; shipment can be done in small batches; quotas are not needed for costs of storing grain in elevator warehouses, which are scarce. Transportation of grain cargoes in containers makes it possible to ensure: the transshipment of grain from transport into containers; the possibility of surveying and certification; customs support and clearance; installation of freight, and corresponding booking. At the same time, specialized handling equipment and machines are used for goods transshipment in the company's containers, such as screw reloaders, pneumatic conveyors, etc. [24].

Container exports offer benefits to moving agricultural products through the presence of empty import containers that can be transported, making available domestic "dry ports" more critical in international supply chains. The document [25] highlights the impact and challenges of increasing container transportation for agricultural goods from remote areas to foreign markets in relation to operations and management.

Effective supply tracking is critical to managing global trade and logistics. That's why the organization and management of supply chains are constantly moving towards cooperation with intellectual and service focus on coping with the growing complexity of customer requirements – this is evidenced according to research by Giustia R. et al. [26]. An important aspect is resource flow control in logistics and other industries: metallurgy [27] and automobile manufacturers [28]. Such principles should be integrated into building supply chains in emergencies based on the classic distribution approaches of food flows [29, 30] and grain cargoes on multimodal routes [31]. Moreover, Ukrainian ports can be closed anytime to export agricultural products [32]. It will lead to searching for alternative supply chains. Therefore, some of the most possible options for multimodal routes using container delivery technology were reasoned and studied in detail in this research.

2 Methodology

The country's logistics potential is a combination of realized and promising opportunities for creating logistics systems and effective management of material and related flows, which make it possible to improve the economic situation per territory and increase its competitiveness [33]. This definition reflects the main characteristic of the country's logistics potential - using opportunities provided by the country to its logistics systems [33].

In the study, to achieve a goal, we will determine alternative technologies for delivering grain cargo in international traffic – Ukraine – Europe, considering the possibilities lack using seaports. The supply uses the road, railway transport, and related terminals. The using containers possibility for transportation will be considered. To define the least costly option, it is proposed to apply mathematical modeling with regression model determination based on selected impact parameters.

Based on information analysis of 10 companies operating in grain cargo logistics, statistical data were obtained on parameters of applications from customers: grain cargo order volume; transportation distance during input (output) cargo flows; transportation distance (mileage) by trunk transport. The selected parameters are considered in the interval view. This study defines a number of conditions: 1) all demand characteristics for senders and recipients of grain cargo are known; 2) the delivery process participants are grain elevators, transport companies (carriers), and railway; 3) the used resources characteristics (containers, railway-wagons, trucks, terminals) are determined; 4) the control system determines service priorities according to product readiness rate; 5) customs authorities take an active part in process control of frontier across.

Consider three alternative technologies for delivering grain cargo in international traffic - Ukraine - Europe, excluding regular delivery through ports.

The first technology is considered from the moment grain trucks unload at elevators, then batches of grain cargo are stored until the moment arriving grain trucks at the elevators (Figure 2). The next logistic operation - cargo batches are loaded into grain railway wagons. Then, several wagons are sent to sorting railway stations, where completed trains depart to frontier stations. At this station, wheel sets are changed to "European" ones, and appropriate documents are drawn up with established cargo checks. After that, trains go to European destination stations, where cargo is unloaded and stored. Further, grain trucks supply grain cargo to recipients.

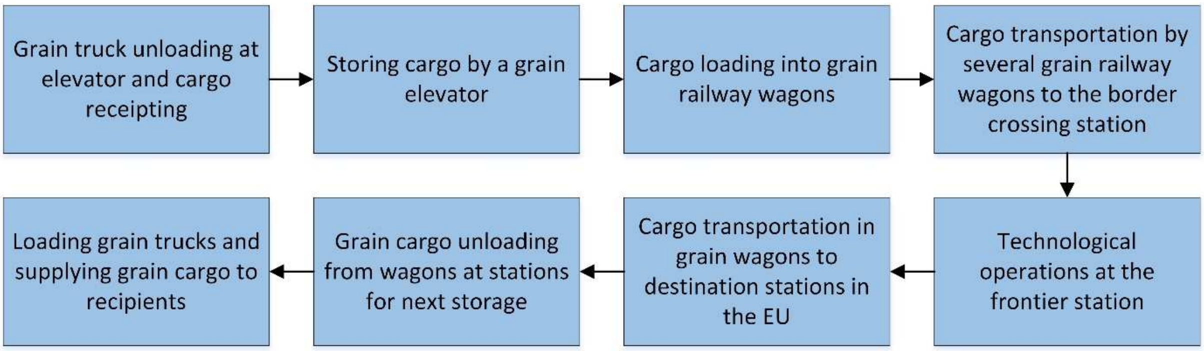

Figure 2 Schematic representation for options of grain cargo delivery along the routes Ukraine - Europe - "Technology 1"

Logistics companies use the second technology for unloading grain trucks moment at elevators. Batches of grain cargo are stored until containers are supplied to loading areas, and then containers are loaded (Figure 3). Further, containers are stored for some time in warehouses (elevators). They are loaded onto mobile railway platforms, and then formed departure of several railway wagons is sent to sorting stations, where a completed train is heading to frontier stations. At these stations, containers are transferred to platforms of "European" carriers, and appropriate documents are drawn up. Afterward, the trains go to destination stations in the EU, where containers are unloaded and stored. From storage areas, containers are loaded onto special vehicles and transported to consignees, where grain cargoes are unloaded from containers.

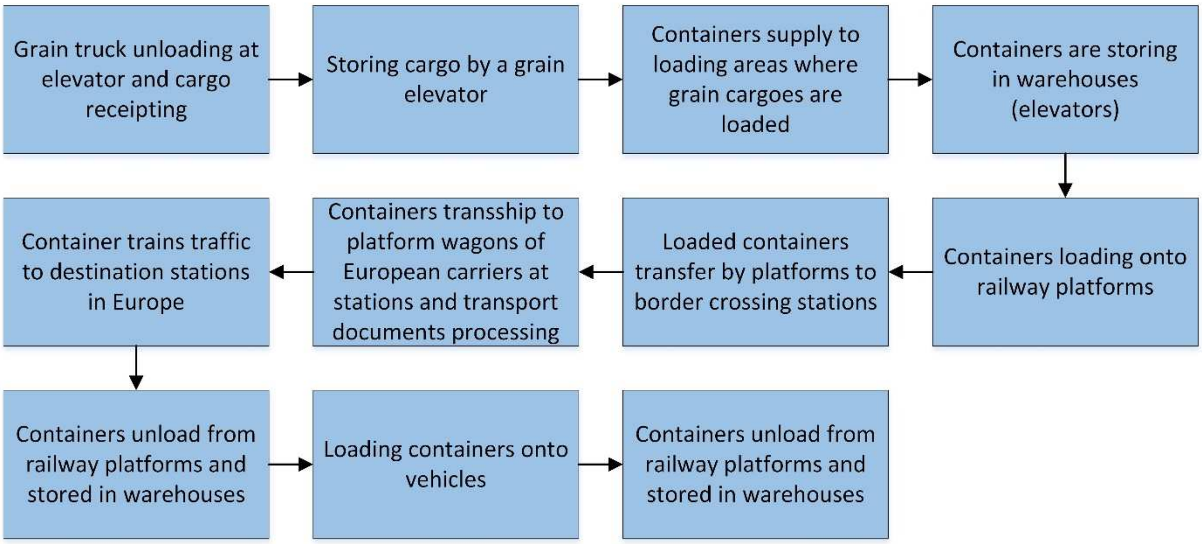

Figure 3 Schematic representation for options of grain cargo delivery by containers along the routes Ukraine - Europe - "Technology 2"

The third technology also begins with grain trucks unloading at elevators. Batches of grain cargo are stored until containers are supplied to loading zones, and containers located on container trucks are loaded with grain cargo (Figure 4). Further, these vehicles go to state borders, crossing frontiers with customs operations passaging. Special trucks with containers follow by European Union territory. Containers are unloaded from vehicles to warehouses (elevators) in Europe. Then, after storing grain cargo in containers at warehouses, they are transferred from containers to grain trucks based on orders, which then transport cargo to consignees and are unloaded at their recipient points.

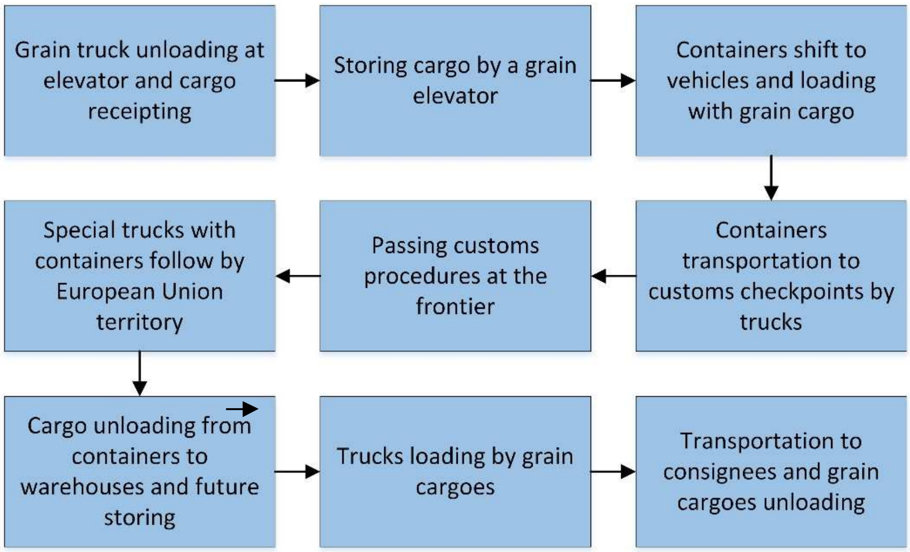

Figure 4 Schematic representation for options of grain cargo delivery by containers along the routes Ukraine - Europe - "Technology 3"

Determination of rational technology of grain cargo delivery in containers is proposed to be carried out according to the estimated indicator - total costs (Z_s), which form values set off a certain ith type of cost for each considered element of the technology

$$Z_s = \sum_{i=1}^{n} Z_i, \forall n = 1, \dots, 8. \quad (1)$$

The following parameters influence the estimated indicator: grain cargo order volume (Q_R); transportation distance during input (output) cargo flows (L_d); transportation distance (mileage) by trunk transport (L_m); time parameters of operations execution (t_{oe}); performed operation cost (S_{oc}).

To achieve the proposed goals of research, a mathematical model has been designed for rational technology determining during grain cargo delivery, which takes into account: the container loading (unloading) costs ($Z_{u(l)}^{cont}$); costs for loading (unloading) and reloading of grain cargo (container) to (from) a vehicle (truck, wagon) of corresponding transport types ($Z_{u(l)}^{vec}$); costs of grain cargo (container) storage in the warehouse and technological idle time for corresponding transport (Z_{st}^{c}); transportation costs of grain cargo (container) by vehicle type (truck, wagon) in the corresponding transport kind in Ukraine and Europe (Z_{tr}); waiting for costs for grain cargo (container) shipment by corresponding kinds of trunk transport (Z_{exp}^{tr}); document processing costs for grain cargo (container) delivery (Z_{d}^{cl})

$$Z_s = Z_{u(l)}^{cont} + Z_{u(l)}^{vec} + Z_{st}^{c} + Z_{tr} + Z_{exp}^{tr} + Z_{d}^{cl}. \quad (2)$$

The container loading (unloading) costs are taken into account: container loading (unloading) average cost with grain cargo ($C_{u(l)}^{cont}$); loading (unloading) time of grain cargo in (from) containers per one ton ($t_{u(l)}^{cont}$)

$$Z_{u(l)}^{cont} = C_{u(l)}^{cont} \cdot t_{u(l)}^{cont} \cdot Q_R, \forall Q_R = \{20; 280\}. \quad (3)$$

The costs of loading (unloading) and reloading of grain cargo (container) to (from) a vehicle (truck, wagon) of the corresponding transport kind shall be taken into account: average cost of loading (unloading), reloading to corresponding transport kind (i) at a certain point (j) (container storage warehouse, railway sorting station) ($C_{u(l)ij}^{c}$); loading (unloading), reloading of corresponding cargo (container) quantity ($t_{u(l)ij}^{c}$); limit quantities of transport kinds (k); quantity limit of cargo tranships points according to corresponding delivery schemes (f); quantity of cargo (containers) loaded (unloaded) on (from) corresponding kind transport at a certain point (n_{contij})

$$Z_{u(l)}^{vec} = \sum_{i=1}^{k} \sum_{j=1}^{f} C_{u(l)ij}^{c} \cdot t_{u(l)ij}^{c} \cdot n_{contij}, \forall k = \{1; 2\}; f = \{1; 20\}. \quad (4)$$

The costs of storing grain cargo (container) at warehouses and technological idle time at corresponding transport kinds must take into account: average cost of storing grain cargo and technological idle time at the corresponding transport kinds at a certain point (warehouse, sorting railway station) (C_{stij}^{c}); time for storage of appropriate cargo (container) quantities and technological idle time using appropriate transport kind at a specific cargo tranship point (t_{stij}^{c})

$$Z_{st}^{c} = \sum_{i=1}^{k} \sum_{j=1}^{f} C_{stij}^{c} \cdot t_{stij}^{c} \cdot Q_R, \forall k = \{1; 2\}; f = \{1; 20\}. \quad (5)$$

The costs of transporting grain cargo (container) by a vehicle (truck, wagon) belonging to corresponding transport kinds in Ukraine and Europe are taken into account: transporting grain cargo (container) average cost by corresponding transport kinds on a specific chain ($C_{tr.ir}$); cargo tranship points quantity limit according to the corresponding delivery scheme (w); corresponding transportation distances (input (output) cargo flow for long distance) of grain cargo (container) by connected transport kind in a specific chain ($L_{tr.ir}^{d,m}$)

$$Z_{tr} = \sum_{i=1}^{k}\sum_{r=1}^{w} C_{tr.ir} \cdot L_{tr.ir}^{d,m}, \forall k = \{1;2\}; w = \{1;4\}; L_{tr.ir}^{d,m} \in L_d \cup L_m. \quad (6)$$

Awaited shipment costs for grain cargo (container) using corresponding trunk transport kinds shall be taken into account: awaited shipment average cost for grain cargo (container) using corresponding trunk transport kinds at a specific cargo transship point ($C_{exp.ij}$); waiting time for shipment of grain cargo (container) using the corresponding transport type at a certain point ($t_{exp.ij}^{tr}$); impact-factor influence on idle time using corresponding transport kinds at a certain point ($K_{inf.ij}$)

$$Z_{exp}^{tr} = \sum_{i=1}^{k}\sum_{j=1}^{f} C_{exp.ij} \cdot t_{exp.ij}^{tr} \cdot Q_R \cdot K_{inf.ij}, \forall k = \{1;2\}; f = \{1;20\}; K_{inf.ij} = \{1.1;1.5\}. \quad (7)$$

The document processing costs of grain cargo (container) delivery are taken into account: issuing documents costs for cargo delivery by a certain transport kind ($C_{d.i}$); insurance costs for goods supplied by a certain transport kind ($C_{ins.i}$); customs clearance cost per vehicle (C_{cost}^{tr}); customs clearance cost of grain cargo (C_{cost}^{c})

$$Z_d^{cl} = \sum_{i=1}^{k}(C_{d.i} + C_{ins.i}) \cdot n_{cost} + C_{cost}^{tr} + C_{cost}^{c}, \forall k = \{1;2\}. \quad (8)$$

First, to solve problems using the proposed methodology, it is necessary to carry out a statistical data assessment from 10 companies operating in the Ukrainian market. Order flows for 2021 are used as input data because the current situation doesn't give any opportunity to receive alternative information about recent amounts of transportation. The variables are the following flow characteristics: amounts of grain cargo order, transportation distance during input (output) cargo flow, and transportation distance by trunk transport. The values were obtained by analyzing orders for grain goods delivery from Ukraine to the European Union, and the total number of orders (observations) equals one hundred.

3 Result and discussion

To obtain the most reliable data about value changes of technological parameters describing processes of container delivery on certain supply chains, the required observations sample is determined (Table 1).

Table 1 Main mathematical characteristics of supply chains

Parameter	Grain cargo order amount (t)	Transportation mileage during input (output) cargo flow (km)	Transportation mileage due to long-distance supply (km)
Expected value	150	40	1553.5
Standard deviation	126.80	56.05	438.05
Measurement error	7.50	2.00	77.68
Sample size	92	97	55

The correlation between the two variables was estimated by Chi-square. When using Statistica software, calculations were made to determine the distribution laws for parameters of input order flows. It has been established that their values are distributed according to the normal distribution of random variables. Three factors were established influencing estimated indicators, and minimum and maximum values were determined using formulas (2-8). The last was found by evaluating selected values from three parameters (Table 2). Based on these data, an experimental plan was completed according to obtained statistics (Table 3).

Table 2 Exposure factor variation levels

Value levels	Grain cargo order amount (t)	Transportation mileage during input (output) cargo flow (km)	Transportation mileage due to long-distance supply (km)
Minimal	20	15	312
Maximal	280	65	2795

Table 3 Levels of influence factor variation (actual values)

Observation series	Variation levels		
	Grain cargo order amount (t)	Transportation mileage during input (output) cargo flow (km)	Transportation mileage due to long-distance supply (km)
Test 1	20	15	312
Test 2	20	15	2795
Test 3	20	65	312
Test 4	280	15	2795
Test 5	280	15	312
Test 6	280	65	312
Test 7	20	65	2795
Test 8	280	65	2795

Regression analysis was performed by two function types: linear and power. Microsoft Excel software was used to design proposed model types, using a built-in program for calculating regression. In this study, regression analysis was performed using established function types for each technology. It is determined that the linear function will be best according to mathematical analysis since the criteria value "R-square" is maximum and equal to 1 (for all three cases). Evaluation parameter values checked the value of the corresponding coefficient for the linear type regression model. They are adequate, except for the free member of the second model. This indicator is not considered when designing the linear model "Technology 2" (Table 4).

Table 4 Regression models for each supply chain option

Supply chain option	Regression model
"Technology 1"	$Z_{s1} = 500 + 511.44 \cdot Q_R + 45 \cdot L_d + 27.5 \cdot L_m.$
"Technology 2"	$Z_{s2} = 493.77 \cdot Q_R + 42 \cdot L_d + 18 \cdot L_m.$
"Technology 3"	$Z_{s3} = 1000 + 310.7 \cdot Q_R + 45 \cdot L_d + 37.8 \cdot L_m.$

The obtained regression models were used to calculate choosing criteria for rational grain cargo delivery technologies (Figure 5). Thus, input data are used as maximal and minimal input order flow parameter values.

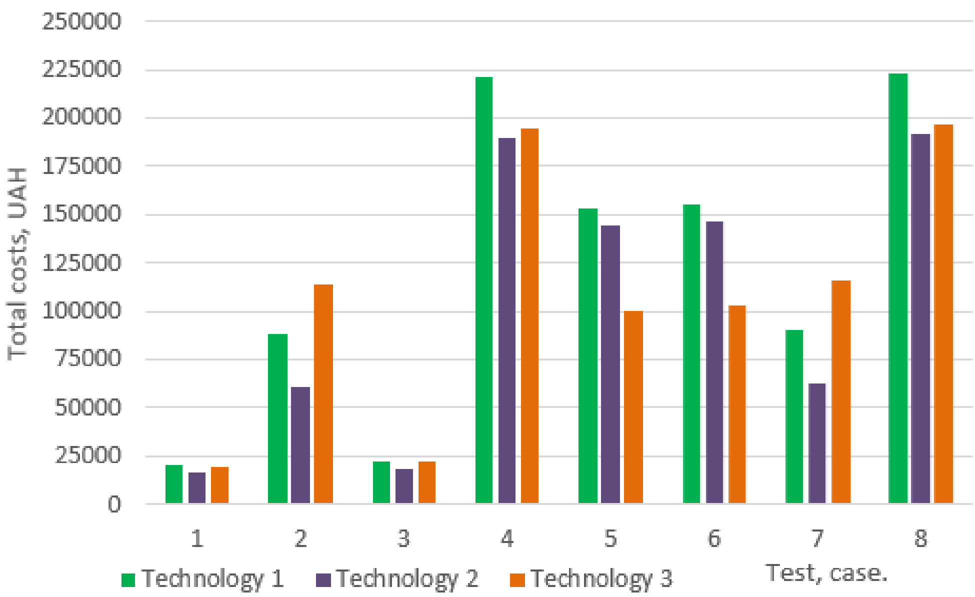

Figure 5 Dependence diagram of total costs for grain cargo delivery in containers on routes from Ukraine to Europe from values combinations of corresponding input parameters for each experiment test

Costs were compared for each technology. It helped to determine more economical options for effect according to combinations of influence parameter values (Table 5). The second technology (transportation of grain cargo in containers by long-distance rail transport) is less expensive than Technology 1 (transportation of grain cargo in grain wagons by long-distance rail transport), with all combinations of influence parameter values, with the greatest effect being 32195.10 UAH. The greatest effect with all possible combinations of comparison is 52874.60 UAH. It is possible when using "Technology 2" compared to "Technology 3" (transportation of grain cargo in containers by trucks) at maximum distances and minimum volume of grain cargo order.

Table 5 Results of economic effect comparing

Observation series	Effect (UAH)		
	Comparing results for "Technology 1" and "Technology 2"	Comparing results for "Technology 1" and "Technology 3"	Comparing results for "Technology 2" and "Technology 3"
Test 1	3862.40	301.20	-3561.20
Test 2	27450.90	-25273.70	-52724.60
Test 3	4012.40	301.20	-3711.20
Test 4	32045.10	26918.70	-5126.40
Test 5	8456.60	52493.60	44037.00
Test 6	8606.60	52493.60	43887.00
Test 7	27600.90	-25273.70	-52874.60
Test 8	32195.10	26918.70	-5276.40

4 Conclusions

This research represents the results of conditions determining under which carriers (grain traders, supply companies) can choose a rational version of the technology for delivering grain cargo using containers by Ukraine-Europe routes. For this, a methodology was developed that included the following elements: alternative options design for technologies of grain cargo supplying; parameters definition for selection evaluating of an effective variant; creating mathematical models for values determining estimated parameters; modeling and evaluating results.

It was proposed to consider this process using three options of their organization with the participation of automobile, railway transport, and corresponding terminals to determine the rational option of grain cargo delivery by containers. Data from 10 companies to form these schemes that organize grain cargoes and containers delivering from Ukraine to Europe were used. The designed options consider the possibilities of using elevators and container areas on Ukrainian territory for storing grain cargo.

Mathematical modeling was the most promising approach for correctly describing the specifics of supplying grain cargo in containers. This nuance improves understanding of the complexity of cause-and-effect logical relations corresponding to certain supply chains. That's why, as a parameter for selecting an effective grain cargo supply chain in containers, the total costs for the delivery of grain cargo were selected considering the restrictions.

A full-factor experimental plan was developed for the three selected parameters, consisting of eight series experiments. At the same time, various combinations of external impact parameters were used, such as grain cargo order volume; transportation distance during input (output) flows; transportation distance by main multimodal kind of transport. Regression analysis was performed by functions of two types: linear and power. It was found that the linear function model is most adequate because the “R-square” value is equal to one.

Regression models of the corresponding type were built for three options for delivering grain cargo in containers on routes from Ukraine to Europe. The effect-determining results showed that “Technology 2” when compared with “Technology 1” at all combinations of values of technological parameters, will have a positive result – the total costs are less (the highest effect level is 32195.10 UAH at maximum values of input parameters).

Future studies will explore other opportunities for designing grain and food supply chains using river routes that will be compared with the models created and obtained results of the current investigation. Such perspectives allow logistics companies to offer alternative supply chain options depending on priority terms specified in requisitions. It improves responsiveness to fluctuations in demand and resource optimization used in the process by all participants in supply chains.

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