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ORIGINAL PAPER

IMPROVEMENT OF MULTIMODAL TRANSPORTATION BASED ON LOGISTIC PRINCIPLES

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ABSTRACT. Relevance of the study: As the experience of advanced countries shows, the development of the economy in our country, in particular, in the transportation services market, is associated with the development of interaction between all types of transport. Thus, in modern conditions, for the growth of the role of railway transport, multimodal transportation, which is important for the interaction of Ukraine with the countries of Europe and the East, is becoming important and will also help minimize costs and preserve the environment. Therefore, the issues of evaluating the introduction of multimodal transportation with logistic principles are discussed in the article. It is shown how to determine the marginal substitution rate in the conveyance type while using various modes of transport, based on the utility function and transportation costs.

Purpose of the study: The purpose of the article is to develop measures to improve the functioning of parts in multimodal freight delivery routes by minimizing transportation costs, taking into account quality indicators. For this purpose, the following tasks have been set and are being solved: to develop a model for evaluating the efficiency of using different modes of transport with optimal costs; to choose a method for estimating the optimal delivery route and freight volumes; to evaluate the efficiency of transportation technology based on a qualimetric indicator.

Approaches: An approach to a comprehensive evaluation of the effect from the activities of transport enterprises in multimodal transportation based on cost optimization, with the qualimetric indicator, and aimed at maximizing the satisfaction of shippers' requirements is offered when determining the route of such transportation parameters as the cost and the quality of freight delivery.

Results: The results of the theoretical generalization and analysis of approaches to the formalization of the functioning process in multimodal transportation systems for the delivery of goods by rail and road modes of transport are presented in the article. **The significance of the results.** The materials in the article are of practical value for employees of transport and logistics companies and enterprises, scientists, and pedagogical workers to improve their professional level.

Keywords: multimodal transportation, railway transport, principles of logistics and qualimetry, vehicle

INTRODUCTION

Transport plays a significant role in the world economy, uniting cities, countries, and continents, contributing to the development of countries as a whole and their entry into the world market. The development of transport infrastructure contributes to the economic, social, and political component of the country's life spheres.

In modern conditions, there is a drop in the volume of transportation by rail, primarily due to the martial law in our country, as well as a drop in industrial output, a decrease in domestic demand due to a decrease in purchasing ability.

Even under such conditions, according to the State Statistics Service of Ukraine, most of the freight transportation, domestic and international, is carried by rail (State Statistics Service of Ukraine, 2022). Consequently, rail transport remains as the leading transport for

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mass cargo transportation due to its reliability, competitiveness, and efficiency for long-distance transportation (Krasheninin and Shapatina, 2016).

Currently, the development of the transport system is increasingly correlated with the mutually beneficial interaction between different modes of transport, with a special place being occupied by multimodal transportation. This mode of freight transportation is carried out on the basis of a multimodal transportation agreement, while a single transportation document (document of multimodal transportation of cargo) is used throughout the route. The geography of Ukraine, which is located at the intersection of international transport corridors and is a connecting link between the European countries and the east, does play the important role.

The processes of globalization in the Ukrainian economy set the task to use rationally using the potential of the economic and geographical position, the effective implementation of which will contribute to obtain economic benefits from participation in international transportation, as well as to create new influence mechanisms on the world economic processes. The main trends in the development of the freight transport organization on the world's railways are associated with the expanded use of specialized rolling stock and the increase in transportation in mixed schemes (multimodal, intermodal, piggyback and bimodal transportation) mainly in international traffic. Multimodal transportation, as world experience shows, is one of the most promising areas for expanding the range of transport services.

Multimodal transportation is carried out with the participation of two or more modes of transport, while competing modes of transport, the main ones being road and rail, are combined in a single delivery chain, using their strengths. Therefore, we ensure a constant influx of new customers, which is a lifeline for the Ukrainian railway industry, because several international transport corridors pass through its territory.

In recent years, the policy of JSC "Ukrzaliznytsia" has been striving to increase the role of multimodal transportation, which will contribute to the interaction of Ukraine with the countries of the European Union. Recently, the role of multimodal transportation with Asian countries has increased. The number of multimodal runs, namely container trains, that passed in 2021 along the routes of international rail freight transportation China - Europe, increased by 22% compared to the previous year, up to 15 thousand trains. The number of container trains on the China-Western European countries, which runs through the territory of Ukraine, has also increased significantly (the transportation of containers on China-Europe rail routes increased by 66% in 2021, 2022).

To increase the efficiency of freight transportation, it is advisable to have a mutually beneficial combination of rail and road modes of transport, that is, to carry out multimodal transportation.

ANALYSIS OF THE LITERATURE AND STATEMENT OF THE PROBLEM

The introduction and study of the organization of multimodal transportation has a significant place in the domestic and foreign literature, where a wide range of issues is considered.

The experience of some countries confirms the economic efficiency of multimodal freight transport. Thus, the multimodal transport system is considered from the standpoint of its components, purpose, characteristics of the freight transportation organization, as well as the composition of the participants in this system. The main feature of the multimodal transport system is the integrity and consistency of all the processes for the delivery of goods.

It is noted in the articles (Krasheninin and Shapatina, 2021), (Fan et al., 2019) that multimodal transportation ensures the safety and security of goods, delivering them door-to-door, but its main disadvantage is the long time frame for loading and dispatching freights. In scientific developments, the mathematical rationale of such a transportation technology is not fully considered.

In the study (Müller et al., 2021) the main attention is paid to the technological aspect of multimodal transportation based on an intelligent system, but the choice of a fright delivery route as one of the components of this transportation is not substantiated. The article (Wronka, 2017) notes the sustainability of laying new routes for container trains in the Europe-Asia direction, in the work (Lin, 2019) the methods for choosing the optimal route for freight delivery are determined, while taking into account the impact of carbon dioxide emissions on the environment, however, the criterion of delivery time is not paid attention.

The article (Gremm, 2018) considers a multimodal transport system, compares the cost component in the interaction of transport modes, but does not determine the role of each transport mode in saving transportation costs.

Studies (Kos et al., 2017), (Hao, Yue, 2016) consider the evaluation of effectiveness in interaction between various modes of transport according to the criteria of transportation cost and time, but do not take into account risks and do not substantiate the number of indicators that determine effectiveness at various methods of interaction between vehicles.

It should be noted that the problems of transport technology interaction based on the reduction of transportation costs, taking into account the quality indicator, are still given insufficient attention.

The issues of defining measures to improve the processes of optimizing parts in multimodal freight delivery routes by minimizing transportation costs, taking into account quality indicators based on the principles of logistics and qualimetry remain topical.

THE STUDY OF MUTUALLY BENEFICIAL INTERACTION OF DIFFERENT TRANSPORT TECHNOLOGIES

The introduction of multimodal transportation poses new challenges for the strategic development of the Ukrainian transport industry, which requires the development of new approaches to the development of transport technologies.

Currently, one of the major challenges for rail transport is to strike a balance between an unpredictable market and making consistent profits by providing new services to customers. Ensuring highly efficient and profitable operation of the industry, its successful operation in the transport services market, due to the uncertainty and dynamism of its development, poses many challenges for the railway. They include forecasting market situations and choosing the optimal strategy, taking into account the possible behavior of transport product consumers in a competitive market environment. It is the basis for carrying out activities to attract customers to the railway transport, planning the need for transportation resources, and income that the railway can receive from the transportation of goods.

Models of the behavior of the transport system and consumers of transport product in market and especially conflict situations, built on the basis of market research, can become an effective tool for solving these difficult tasks.

With all the differences of mathematical models describing market processes, in terms of economic content, problem setting, and methodological approaches, they are united by one common goal - to determine the best strategy for the behavior of both the carrier and the client in the transport product sales market. It makes it possible to build a transport policy taking into account the interests of cargo owners and, ultimately, to increase the volume of transportation and improve the economic situation of the railway.

Depending on the state of the market environment, the processes occurring in the transport market can be described by different models: dynamic based on differential equations, probabilistic, and built on expert systems. As the analysis of foreign experience shows, it is possible that the behavior of market entities in a competitive transport environment is well described by models using game theory methods. This method is based on an intuitive idea of the optimal value, that is, the obtained optimal value is not unique, the solution of the problem will differ depending on the conditions (Panchenko and Rezunenko, 2015, P.2).

In addition, analytical models using mathematical programming methods, in particular linear programming, have become widely used to reflect fairly stable stationary processes. The solution of the linear programming problem occurs when optimizing for a certain indicator if an objective function and restrictions are available.

Recently, attempts have been made to describe the functioning of the market environment under conditions of pronounced uncertainty by the methods of artificial intelligence theory using expert systems. This system can process, apply, and improve the acquired knowledge and skills, has learning capability (Savchenko and Synelnikov, 2017).

Multimodal transportation is a complex transport and logistic process that provides the rationale for an effective way to implement the transport process, determining the optimal route, the role of each transport, organizing the interaction between certain modes of transport and cargo transshipment points, processing the necessary documents, taking into account various risk factors, etc. Therefore, it should be noted that this type of transportation is one of the most difficult methods of transportation in the organizational aspect.

With that in mind, let us consider the following model, which takes into account a complex of market situations and allows us to evaluate which combination of several interchangeable modes of transport the consumer will choose as optimal for him.

Using this model, it is possible to solve optimization problems related to the search for a certain equilibrium point for market processes under the conditions of a compromise between opposing trends and subjects of the transport market. With it, one can predict the motivation of the potential customers actions and set up a predicted marketing policy.

This is the so-called consumer model, which characterizes the expediency of interchangeability of one transport mode with another in terms of providing multimodal transportation (Panchenko and Rezunenko, 2015, P.1).

Figure 1 shows a graphical interpretation of the substitution of transport modes, which demonstrates a curve U that reflects the utility function of transport modes for the consumer of its services. The ordinate axes x_1 and x_2 represent the interchangeable modes of transport and their services, which can be obtained from the chosen mode of transportation, and the ratio x_1 / x_2 shows the marginal rate of substitution of one transport mode by another, and the shaded area, the admissible substitution zone.

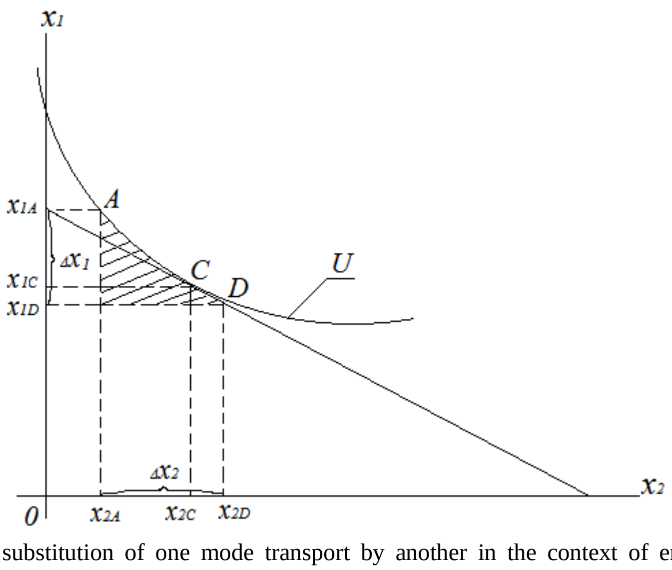

Fig. 1 Graphical interpretation of substitution of one mode transport by another in the context of ensuring multimodal transportation

Mutual substitution of transport modes makes sense only on the section AD of the utility function curve. Marginal substitution is possible only with the consumer interests of the market entity.

The segment Ox_{2A} characterizes the minimum amount of consumer interests from vehicles x_2, which the consumer cannot refuse, and Ox_{1D} – the minimum amount of consumer interests from services necessary for the consumer x_1.

When replacing one mode of transport with another, the consumer should take into account their resource capabilities. They are estimated by the so-called budget constraint, which is the sum of goods and services prices and transport tariffs on numerical values of interchangeable and complementary utility. On the graph, this is a straight line that affects the curved utility function at the equilibrium point C.

Moreover, this point should be in the allowable substitution zone and should characterize the position of the consumer's economic equilibrium in terms of the best substitution of transport modes for accepting prices and tariffs. It also shows a kind of compromise for opposing tendencies in the processes of replacing one mode of transport with another in order to obtain the maximum economic benefit for the consumer. The slope ratio of the direct budget constraint to the y-axis is numerically equal to the ratio of the prices which are considered as tariffs for the modes of transport to each other. From an economic point of view, the budget constraint shows how to distribute freights between two modes of transport within a divided amount of money.

The curve describing the utility function reflects the possible combinations of two economic services that provide the same benefit to the consumer and is a graphical interpretation of the maximized (or minimized) objective function. Moreover, the coordinates of the equilibrium point represent the optimal solution to the problem of substitution, for example, railway transport for automobile transport or vice versa.

Having obtained on the basis of marketing research the numerical characteristics of the potential client behavior motivation, it is possible to determine the specific type of objective function and calculate the parameters that will characterize his possible actions. Figure 1 shows the combined use of transport modes at the equilibrium point x_{2C} and the corresponding level of substitutable services x_{1C}. The value of these coordinates with the adopted pricing policy shows the optimal combination for the consumer of using road and rail transport when transporting freights.

As can be seen from the consideration of this model, for the consumer, first of all, it is important to realize their interests in the conditions of monetary restrictions. But for vehicles, to satisfy the conditions of competitiveness, it is necessary to ensure the minimum costs for their operation. From the point of view of operating costs, it implies the choice of the optimal route of movement, which reduces the cost of energy carriers. In addition, the carrier receives its profit from the volume of the transported cargos. In addition, the faster transportation is completed, the more vehicles can offer their services. That is, to evaluate the efficiency of vehicles, the following main aspects should be taken into account: the optimal route, the maximum load, and the maximum delivery speed of the freight or services to the client.

To solve multidimensional problems related to the evaluation of the behavior in the transport market, linear programming methods are effective. When different types of freight using some transport schemes, the application of graphic-analytical methods, due to their features, becomes practically impossible. Meanwhile, the algorithms of the classical resource allocation problem, formulated in terms of linear programming, have practically no restrictions on solving a multidimensional distribution problem (Panchenko and Rezunenko, 2015, P.1).

Let us formulate such a problem on the interests of transport consumers. Let us assume that from several methods of the delivery of finished products, the sender must choose their optimal combination, which ensures the minimum total cost of transportation. Natural restrictions are imposed on the volume of traffic, determined by the railway contacts with the sender. In addition, the sender's resources to pay for tariffs are also limited. In this case, the solution is resolved into such a distribution of traffic volumes by modes of transport, in which the objective function expressing costs by tariffs will have a minimum value.

In the event of a conflict situation associated with a drop in the income of the railway, it becomes necessary to increase the level of the tariff for transportation, then the total profit of the railway may increase. However, if the level of tariffs is reduced, then the volume of traffic and the total profit will increase slightly. Consequently, with a decrease in the total profit of the railway with an increase in tariffs, it is advisable to reduce the level of tariffs for transportation.

Thus, the ideology of interchangeability of each transport mode in the chain of freight delivery using multimodal technology is clear.

THE RESULTS ON DETERMINING THE LEVEL OF EXPENSES FOR TRANSPORTATION TECHNOLOGIES

The most important indicator that influences the choice of delivery method is transportation costs. At the same time, an important role is assigned to the choice of the delivery route and the volume of freight transported. When determining the route of transport, methods such as the Dijkstra's algorithm, the salesman problem, the ant colony algorithm, the transportation problem, the genetic algorithm, etc. are used.

Dijkstra's algorithm is used to find the shortest path from one point of the graph to another. Dijkstra's classical algorithm can only be applied to graphs without edges of negative length. When solving the salesman problem, a criterion for choosing the best route is selected, it is either the shortest or the cheapest, or a combination of criteria and the corresponding distance and cost matrices. The ant colony algorithm is one of the efficient polynomial algorithms to obtain an approximate solution to the salesman problem. The specified salesman problem and the ant algorithm are heuristic, when solving them, not the most efficient route is found, but an approximate solution, however, due to the number of the algorithm repetitions, a more accurate result can be obtained (Denardo, 2003).

The solution of the transport problem belongs to the problems of linear programming. The solution of the transport problem is to find the optimal plan for transporting the uniform goods from points of production to points of consumption, the efficiency is evaluated by the criterion of the lowest cost of transportation (Panchenko and Rezunenko, 2015, p.1). The search for a solution according to the genetic algorithm occurs with the help of "crossing" and a similar natural selection process. The disadvantage of this method is the necessity to know the background, the gene pool (Oudani et al., 2014).

So, the cost of freight delivery is largely dependent on the choice of the optimal parts of the multimodal route in the freight supply chain. Therefore, one of the tasks to determine the cost indicator for multimodal transportation is to establish the optimal transportation route.

When choosing a mode of transport for the corresponding transport technology of transport in paper (Panchenko et al., 2017) the methods of theoretical qualimetry are used and the transport work is determined expressed in trans. A variety of vehicles does not allow one to estimate their properties in their entirety, so for different modes of transport the range of using technical characteristics is different, therefore, for an objective evaluation of transport technology, a qualimetric indicator is used, taking into account costs in conventional units.

Then, in the implementation of multimodal transportation, we will determine the indicator corresponding to the cost of transportation, taking into account the qualimetric component:

$$C(S_i) = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{B} \delta_i C_i \rightarrow \min, \qquad (1)$$

де $a = \sum a_i$ – departure and destination points;

$b = \sum b_j$ – number of transport types involved in multimodal transportation;

$B = \sum B_k$ – mass of freight delivered by various transport types, t;

S_i – route for the freight delivery by various transport types, km;

δ_i – value of transport types, $\sum \delta_i = 1$;

C_i – indicator of the level of costs for transportation technologies with the qualimetric component, conventional units/tran.

When choosing the transport components in the multimodal freight delivery, the following factors are taken into account: transportation cost, delivery time, frequency of shipments, reliability of compliance with the freight delivery schedule, ability to transport various loads, ability to deliver freight anywhere in the territory (Kysly et al., 2010). According to the above factors, the most competitive variants for freight delivery are railway and road transport.

Therefore, we will consider freight delivery only by ground modes of transport. Let there be a set of freight delivery routes S_i from point a_1 to point a_2 by various types of transport. According to the put task, there are three possible variants to freight delivery: railway transport,, road transport and multimodal transportation. At the same time, part of the freight in a certain volume ΔB_i in places a_i (Fig. 2).

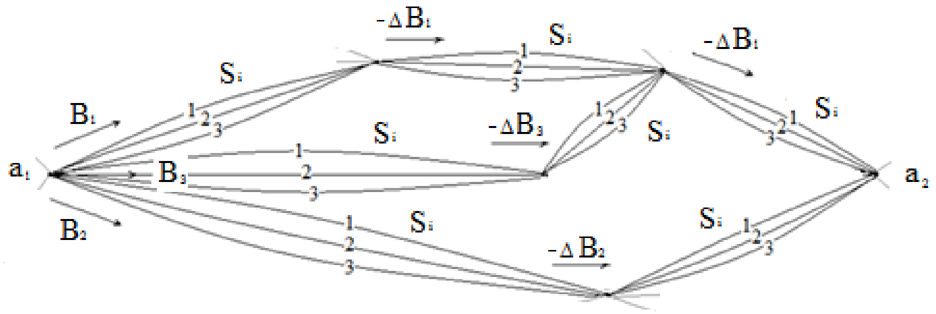

Fig. 2. Example of a random choice of the freight delivery route from point a_1 to point a_2 with different technologies: 1- by railway; 2-by road; 3-by multimodal

Taking into account the above, the formula was transformed for multimodal transportation with the participation of road and rail transport.

$$C(S_i) = \sum_j \sum_i \delta_i \frac{z_i}{A_i \cdot \prod_{i=1}^{m} \lambda_i} \rightarrow \min, \qquad (2)$$

де j – variable corresponding to the freight transportation route;

i – variable corresponding to the transport type, $i = \overline{1, n}$;

S_i – route for the freight delivery by various transport types, km;

δ_i – value of transport types, $\sum \delta_i = 1$;

z_i – transportation costs, conventional units;

A_i – beneficial effect of the transport operation, tran;

$\prod_{i=1}^{m} \lambda_i$ – coefficients reflecting the commercial return, reserve of dynamic properties, the ratio of vehicle maintenance costs over the service life to its cost, time reduction under technological operations, competitiveness and reliability of the vehicle.

Moreover, the beneficial effect is estimated as follows:

$$A_i = B_i \cdot v_i^2 \cdot S_i \to \max, \tag{3}$$

де B_i – mass of freight delivered by various transport types, t;

v_i – speed movement of the vehicle, km/h;

S_i – route for the freight delivery by various transport types, km.

The coefficients $\prod_{i=1}^{m} \lambda_i$ determined accordingly:

coefficient of commercial return λ_{1i}

$$\lambda_{1i} = \frac{p_i}{m_i}, \tag{4}$$

де p_i – load capability of a transport vehicle, t;

m_i – weight of the transport vehicle in the loaded state, t.

coefficient of reserve of dynamic properties λ_{2i}

$$\lambda_{2i} = \left(\frac{v_{max\,i}}{v_{p_i}}\right)^2, \tag{5}$$

v_{max_i} – maximum speed of the transport vehicle with freight, km/h;

v_{p_i} –calculated speed of a transport vehicle, km/h;

coefficient that takes into account the ratio of vehicle maintenance costs for the life cycle to its value λ_{3i}

$$\lambda_{3i} = \frac{k_{v_i}}{c_{v_i}} \tag{6}$$

де k_{v_i} – costs on maintenance of transport vehicles during the service life, UAH.;

c_{v_i} – transport vehicle cost, UAH.

coefficient that takes into account the reduction of time under technological operations λ_{4i}

$$\lambda_{4i} = 1 - \frac{r_i}{t_i}, \tag{7}$$

де r_i – increase in the value of time under technological operations by various technologies, h.

t_i – time value under technological operations using the basic technology, h.

The coefficient of competitiveness λ_{5i} and reliability of the vehicle λ_{6i} is determined in accordance with (Puzankov and Chetvergov, 2003), (Vasilevsky and Podzharenko, 2010), (Shapatina, 2013), (Lavrukhin et al., 2017).

Then the indicator that corresponds to transportation costs, taking into account the qualitative component for multimodal transportation, is determined.

$$C(S_i) = \sum_j \sum_i \delta_i \frac{z_i \cdot \left(1 - \frac{r_i}{t_i}\right)}{B_i v_i^2 S_i \cdot \frac{p_i}{m_i} \cdot \left(\frac{v_{max\,i}}{v_{p_i}}\right)^2 \cdot \frac{k_{v_i}}{c_i} \cdot \lambda_{5i} \cdot \lambda_{6i}} \to \min. \tag{8}$$

Under such limits:

$$\begin{cases} B_i > 0; S_i > 0; \\ \sum \delta_i = 1; \delta_i \geq 0; \\ S_1 \leq S_{ts}; S_2 \leq S_r; \\ S_1 + S_2 + S_3 \leq S_{dp}; \\ 0 < v_{p_i} \leq v_i \leq v_{max}. \end{cases} \tag{9}$$

де B_i – mass of freight delivered by various types of transport, t;

S_i – route for the freight delivery by various transport types, km.

δ_i – value of transport types;

S_1 – route for the freight delivery by rail transport, km;

S_{ts} – distance to the technical station, km;

S_2 – route for the freight delivery by road transport, km;

S_r – distance to the gas station or service station, km;

S_3 – route for the freight delivery by multimodal transport, km;

S_{dp} – distance to the destination point, km;

v_{p_i} – calculated speed of a transport vehicle, km/h;

v_i – vehicle speed movement, km/h;

v_{max_i} – maximum speed of the transport vehicle with cargo, km / h.

It should be noted that to determine the possible B_i and v_i it is necessary to take into account the value of the estimated lift and adjust them accordingly (Rules of grade computations for train service, 1985). In practice, for this, two masses of the composition B_2 and B_3, which are smaller than the critical mass B_1 at the calculated lift, must be set. For them, specific accelerating forces are calculated and a graph is constructed $v_i(S_i)$.

At the end of the largest (estimated) rise, the speeds v_2 and v_3 are obtained. Curves are constructed based on known values of composition masses and speeds $B_i(v_i)$ (Fig. 3).

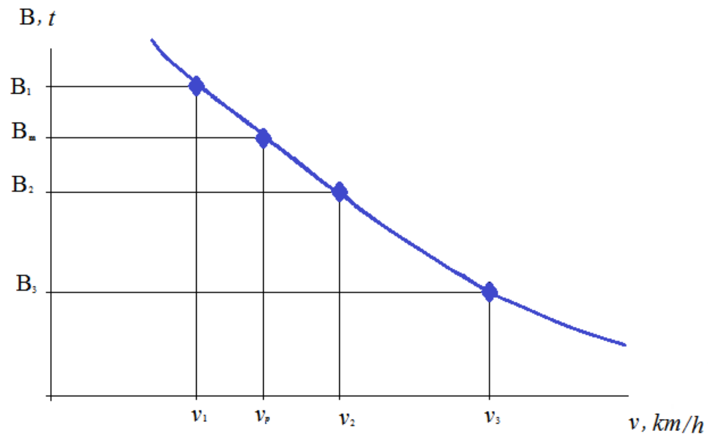

Fig. 3 Determination of the mass of the composition on the critical slope

Using this graph, determine the desired mass of the composition B_m at the computed speed v_p.

In general terms, the solution of this problem can be reduced to a linear programming problem or a dynamic programming problem. If the constraints have a nonlinear dependence, then dynamic programming with constraints that have a linear dependence will use the linear programming method.

It should be noted that the solution of the problem has a multifactorial influence of various factors on the performance of the problem. In analytical form, individual problems can be reduced to a solution to determine the optimal path. But in general, the formalization of such a solution is theoretically difficult to achieve; therefore, this problem is solved using optimization methods according to the structural diagram shown in Figure 4.

The possibility of limiting the volume of freight involves traction calculations. As part of these calculations, the estimated mass of a train or other vehicle, the average technical speed of the delivery of the freight to the place of unloading or transshipment point to another vehicle is determined. On the basis of the above method, the following graphical dependencies were obtained (Figure 5).

Using this nomogram, it is easy for the carrier operator to identify alternative vehicles to provide transportation for customers. Maneuvering these data, it is possible to correct routes, evaluate the critical mass of freight, and limit the speed of obtaining the minimum cost for transportation.

According to the above, when choosing the technology of freight transportation, the importance of each component of the qualitative indicator should be taken into account in any time period when making decisions, the implementation of the choice of the type of transport is shown in Fig. 6.

The results of determining the level of transportation costs by various transport technologies, taking into account the qualimetric component, are shown in Figure 7.

From the dependencies presented, it is possible to choose the optimal technology for freight transport to different delivery routes and a combination of transport types.

Thus, based on the analysis performed, it is shown that the efficiency is affected by the choice of a vehicle, taking into account the range of the optimal values of carrying capacity and the zone of transportation distance based on determining the optimal value of the qualimetric indicator.

In this formulation, the basic principles of logistics are implemented: a systematic approach (coverage of all logistic chains); individualization (adaptation to specific conditions); humanization (modern working conditions and exclusion of harmful effects on the environment); reduction of total transportation costs in market conditions; development of service at the modern level with flexibility, reliability.

So, the main criterion for choosing a route is transportation costs. When solving certain transport problems, it is often necessary to take into account some additional restrictions that were not encountered when considering simple variants of these problems. Recently, transport services have been paying attention to additional criteria, which include, for example, the possibility of receiving an order within a clearly defined time frame, high-quality information support for the order fulfillment process, etc.

Based on the optimal multimodal route obtained in the freight supply chain, cost calculations are made for various technologies of freight delivery, which depends not only on the route, but also on the volume and class of load (Congli and Yixiang, 2016).

Thus, the combination of two transport modes for the multimodal transportation organization will provide the necessary level of quality for the delivery and storage of goods, cost savings, and an increase in the competitiveness of rail transportation. Therefore, for multimodal transport, the cost is calculated taking into account delivery by train, which reduces costs by up to 50% and becomes especially beneficial when transporting bulk freight (Islam D.M.Z., 2014).

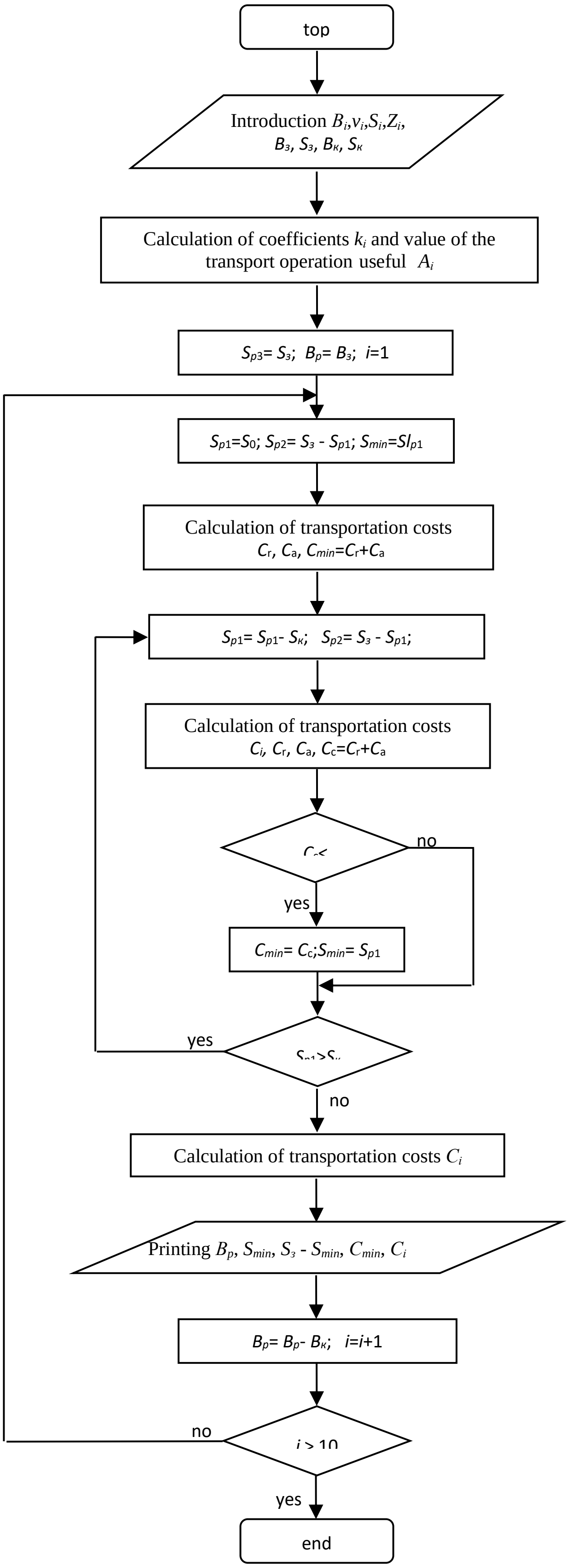

Fig. 4. Structural diagram of the transport technology selection algorithm

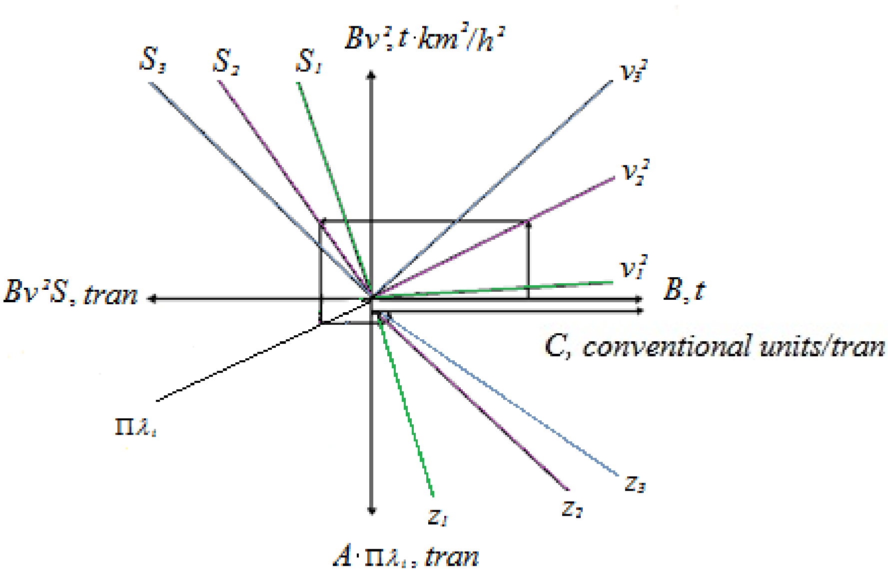

Fig. 5 Nomogram for determining the cost indicator with the qualimetric component

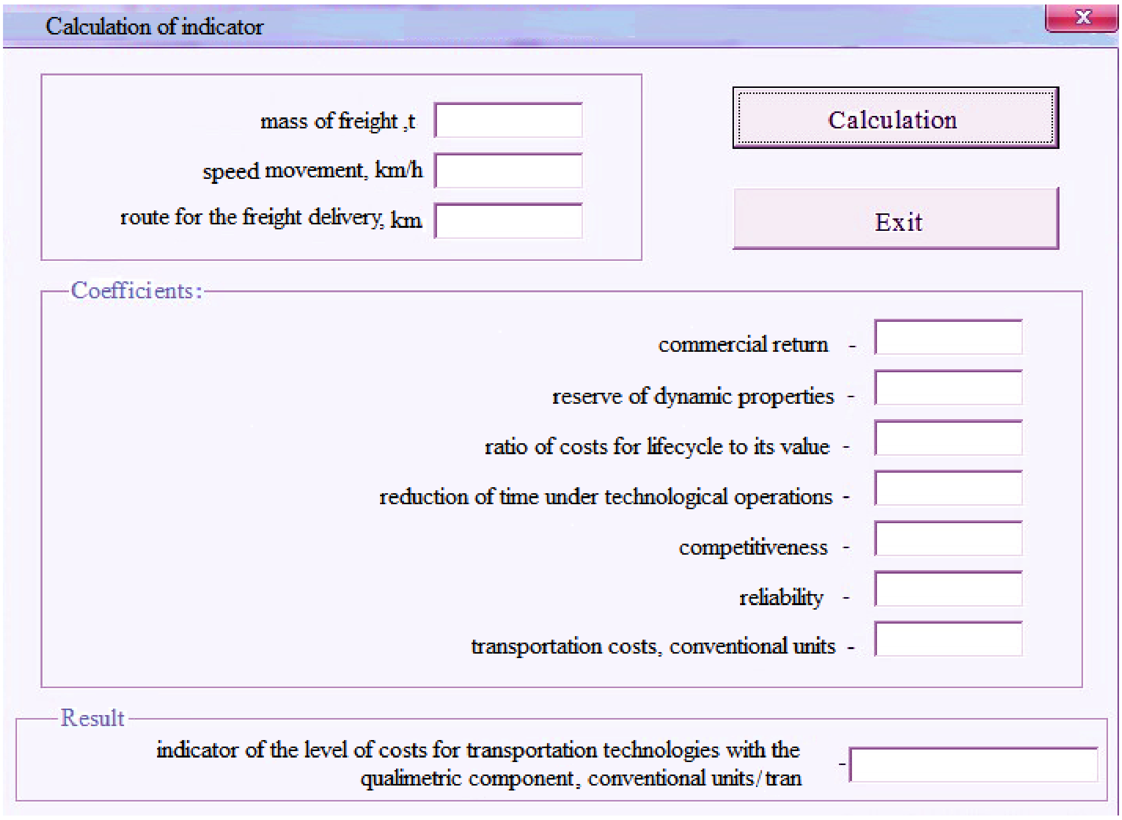

Fig. 6 Implementation of the choice of transportation type taking into account the qualimetric component

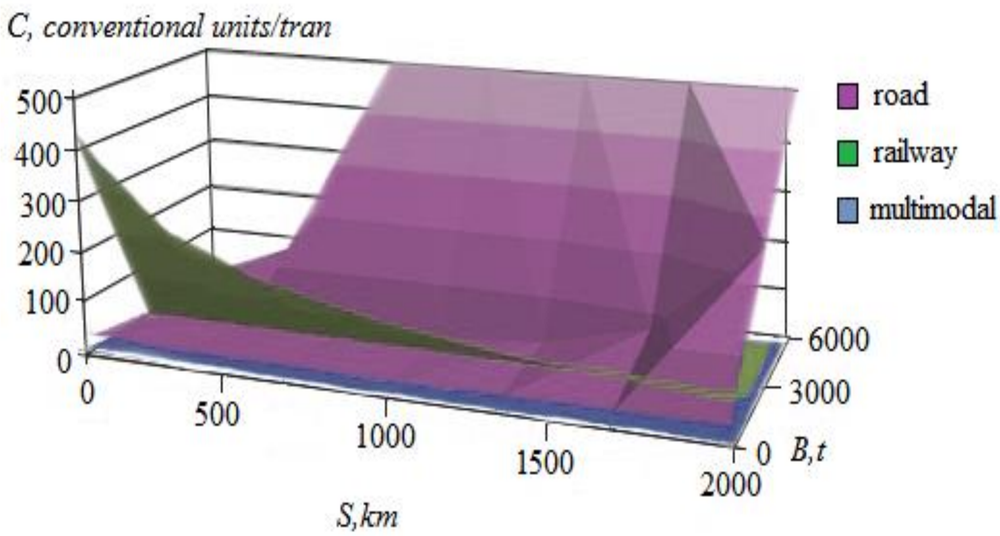

Fig. 7 Determining the level of transportation costs by various transport technologies taking into account the qualimetric component

DISCUSSION

Traditionally, in our country, railway transport occupies a dominant place in transporting large volumes of goods by land, and its work is estimated in terms of gross tons per kilometers. At the same time, the work of maritime transport is estimated by the size of the displacement, i.e., dead weight. However, in a competitive environment, the dominance of one transport mode is almost impossible. Especially when the demand for door-to-door delivery of goods is growing, the combination of transport modes in a single transportation chain becomes important.

It should be noted that the generally accepted criteria used to evaluate the operation of various transport modes do not provide an objective assessment of the transport efficiency, whereas they do not take into account an important factor for users as speed. At the same time, in some studies, attempts were made to take into account the freight delivery speed on the basis of the transport movement unit as a product of the main transport process indicators: the load weight, the distance of transportation, and the speed of freight traffic (Grebenikov et al., 1998). However, this indicator does not fully provide an objective performance evaluation of transport operation, therefore, in the study (Andrianov and Lopatin, 1983), a criterion for evaluating transport work was offered in the form of the so-called "tran" with the dimension tkm^3/h^2. 'Tran' consists of three components: the weight of the transported load, its transportation distance, and the speed square of the freight traffic.

This set of parameters characterizes the essence of the energy of mass transfer, that is, the kinetic energy of movement, equivalent to the work of transfering the load over a certain distance. As can be seen from the dimension of this unit, the dominant factor in the evaluation of transport operation is the speed factor (speed squared), which forms the basis of the transportation intensification process. That is, the unit 'tran' reflects and considers the known laws of nature, according to which work is spent overcoming the resistance forces that change according to quadratic laws of movement speed (Andrianov and Lopatin, 1983).

As world experience shows, in modern conditions, a significant number of freight owners have demanded from the carrier, first of all, to speed up delivery and not necessarily to minimize operating costs, which also shows the importance of taking into account the speed indicator when evaluating transport services. This is also evidenced by the need to solve the problem of improving multimodal transportation technology based on cost optimization, taking into account the qualimetric indicator aimed at maximizing the satisfaction of shippers when determining the route of such transportation parameters as the cost and quality of freight delivery, which are different in nature.

In addition, the results of the study on improving the functioning of the parts of multimodal freight delivery routes by minimizing transportation costs, with qualitative indicators, allow making decisions on the choice of freight transportation technology at a specific point in time, considering the importance of each criterion component (Fig. 5, 6).

The offered qualimetric indicator, with costs in conventional units, has the main advantage over the existing ones (Hanssen et al., 2012), (Steadie et al., 2014), (Mindur, 2021), (Pshinko et al., 2022), while it is systemic in nature, takes into account the integrity and consistency of all freight delivery processes, and evaluates the complexity of vehicle level indicators that have influence on the freight transportation efficiency.

In addition, this indicator can be used both to evaluate the performance of the interaction between road and rail transport, and for other modes of transport due to its complex nature. Its interpretation in graphical form has a convenient visualization in the form of a nomogram.

In the context of changing markets for transport services, it is a necessity to modernize service elements along the entire length of the supply chain. The main task of railway transport in these conditions is to balance the unpredictability of situations in the transport service market (Primachenko et al., 2022).

The current state of infrastructure, the necessity for effective development and coordination of railway, road, and maritime transport requires the continued development of the state transport network. At the same time, the state and degree of using the capacities and infrastructure of these transport modes indicates the presence of contradictions and inconsistencies, which worsen the transport service quality and reduce their work efficiency.

As a result of these tasks diversity, namely: for railway transport, which is one of the largest consumers of energy resources, the priority direction for the development of the industry is the introduction of resource-saving technologies, for road transport – ensuring the mobility of transportation, for maritime transport – the provision of quality services. Therefore, the improvement and development of the national transport potential requires the modernization of infrastructure, increasing the efficiency of transportation technologies in order to increase competitiveness and adapt to European transport standards.

The availability of multifunctional rolling stock is gaining momentum in the world. In particular, in the countries of western Europe and Japan, transportation by hybrid trains or tram-trains designed for both urban and railway traffic has become widespread. In our country, hybrid rolling stock is gradually developed in urban transport as a separate experience. The introduction of such rolling stock will help to prevent the threat of the disappearance of energy supply, reduce emissions of harmful substances into the environment, and ensure resource saving.

As the practice of world experience shows, the main measures to improve the functioning of transport based on logistic principles are real-time supply chain management, the selection and provision of the optimal route for freight delivery, the application of modern vehicles, which is just possible to implement on the specific 'tran" criterion .

Since real-time supply chain management technology allows one to receive data on the vehicles movement, weather conditions in a certain area, the state of roads or access roads, it will help to select the optimal delivery route, reduce time costs, and use energy resources efficiently based on the principle of consistency.

The primary task to improve freight delivery quality remains the task of ensuring the reliability and safety of transportation with the optimal route, which is reflected in additional coefficients introduced to evaluate the quality of transport service.

A promising direction for improving the efficiency of the transport industry is the implementation of transportation based on autonomous vehicles, which provides freight transportation without a driver, thereby reducing the influence of the "human" factor. Such a direction as the freight delivery by aircraft, for example heavy-duty quadrocopters, is gaining currency, the path of which will be selected over existing tracks and other infrastructure elements, ensuring the transportation of both goods and people (China tested a flying taxi drone with a pilot inside, 2022). A promising direction in the development of the logistic transport infrastructure is the introduction of robotics in warehouse operations, while providing access to any hard-to-reach places and having an extended inspection area. This measure allows to significantly increase the efficiency and speed of warehouse processes, ensuring the development of services at a modern level, at flexibility and reliability, also based on the “tran” indicator.

The introduction of such an indicator allows to track possible delays at the points of changing the transport mode and on the lines in dynamics, depending on the arrival time of the freight at a given point on the route, and also determines the optimal route not only by the criterion of costs, but also by the criterion of the transportation duration taking into account the qualimetric indicator.

Thus, to evaluate the quality of the transport technology, the following tasks were solved:

- a criterion for choosing the mode of transport for each section on the route has been formed;

- the optimal route for the freight delivery was determined;

- The value of the quality criterion of transport technology is determined on the basis of the developed algorithm, and a graphical dependence is built, interprets the effectiveness of the interaction between modes of transport for freight traffic.

The criterion for choosing a transport technology based on a qualimetric evaluation takes into account the freight transportation volume, the freight delivery speed, the route distance, the time spent on the moving, downtime during technological procedures, variable freight traffic in different periods of the year. Separately, within the framework of traction calculations, the task of estimating the maximum weight of the train and the average speed of traffic is performed, and based on linear or dynamic programming, the optimal route for the delivery is modeled, the mode of transport is selected, and the interaction between the transport modes is determined. At the same time, restrictions that may arise in case of traffic disruptions due to emergency situations and during repair work are taken into account. Based on the introduction of automated freight traffic management technology, a freight transportation route is selected, considering the network tension and the likelihood of vehicle failure, which will allow the change of route quickly and improve the quality and meet the demands of transportation.

Thus, the implementation of the task to improve the transportation management quality involves determining the optimal route for the freight delivery, searching for the optimal interaction of the transport modes including in particular multimodal transportation. The introduction of modern transport infrastructure technologies based on logistic principles will improve transport operations in general, reduce the impact of crisis situations on the economy, and ensure resource saving.

The resulting procedure for evaluating the quality of transportation management can complement traditional approaches to the formation of transport technologies, including new vehicles. The developed transport technology evaluation procedure can be used for non-discriminatory access to infrastructure.

CONCLUSIONS

The application of the models concerned in the railway marketing services will allow them to evaluate in advance the possible customers’ behavior in the transport service market and to take proactive measures to attract freights to the rail transport more effectively.

Therefore:

1. The model for evaluating the efficiency of using different modes of transport with optimal costs has been formed.

2. As a method for estimating the optimal delivery route and traffic volume, depending on the nature of the constraints, a linear or dynamic programming method is chosen.

The essence of economic efficiency lies in cost savings when designing multimodal freight delivery routes, which are carried out continuously and jointly by different modes of transport, which occur by reducing the time across the entire logistic network for freight delivery at the lowest cost and high quality of services performed for consumers based on a qualimetric indicator. The competitive advantage of the transport multimodality principle is that services are provided by only one carrier, while providing door-to-door delivery, thus becoming less costly and more efficient than when each of the carriers tries to maximize its profit on its own separate site in the logistic product supply chain.

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