DETERMINATION OF FUNCTIONAL CHARACTERISTICS OF CUSTOMS AND LOGISTICS INFRASTRUCTURE IN TRANSPORT SYSTEMS OF INTERNATIONAL DIRECTION

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Summary

Introduction. *Critical analysis of literature sources shows the trends of stable development of integration processes in international production structures. Increasing the production of industrial goods and food requires the creation of new and intensive use of existing infrastructure of production units. Therefore, the development of competitive customs and logistics systems for servicing foreign trade flows is one of the main tasks of the relevant government and commercial structures.* ***Purpose.*** *The peculiarity of the growing volumes of export and transit transportation of goods is the need to involve in the organization of foreign trade supplies of powerful transport hubs with appropriate infrastructure. Taking into account the specifics of the development of economic integration processes, sea trade ports correspond to such opportunities. And intensive use of the existing and creation of the newest infrastructure of subjects of economic activity demands development of technological and structural bases for improvement of transportations of foreign trade cargoes. The article investigates the methodology of forming the infrastructure of customs and logistics systems of export orientation, taking into account the assessment of the competitiveness of transport services.* ***Results.*** *Development and practical use of methods of formation of production infrastructure in transport hubs are based on the principles of economic integration and improvement of transportation processes. It was found that compliance with the terms of accumulation and processing of import and export cargo is an important characteristic for transport hubs. And with the complication of the tasks of transport and customs and logistics services there is a need to form a rational infrastructure of transport systems. The proposed methodology for the formation of the infrastructure of transport hubs provides an opportunity to identify ways to intensive use of existing and the creation of promising production facilities of customs and logistics systems provided the optimal distribution of material resources.* ***Conclusions.*** *In the course of the research new results were obtained to improve the methodology of formation of*

customs and logistics infrastructure in transport hubs. Based on the main provisions of the theory of systems analysis, new and supplemented the existing results of the interaction of individual structural elements of production formations of international orientation. Using the method of simulation modeling, integrated indicators of quality transport service are calculated on the example of export cargo flows. The study can be useful for improving the efficiency of transport services for freight flows in international production structures.

Key words: international transportation, customs and logistics infrastructure, transport systems, foreign trade cargo, transport hubs, economic integration.

ВИЗНАЧЕННЯ ФУНКЦІОНАЛЬНИХ ХАРАКТЕРИСТИК МИТНО-ЛОГІСТИЧНОЇ ІНФРАСТРУКТУРИ В ТРАНСПОРТНИХ СИСТЕМАХ МІЖНАРОДНОГО СПРЯМУВАННЯ

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Анотація

Вступ. *Критичний аналіз літературних джерел свідчить про тенденції стабільного розвитку інтеграційних процесів у міжнародних виробничих структурах. Збільшення обсягів виробництва промислових товарів і харчової продукції вимагає створення нової та інтенсивного використання наявної інфраструктури виробничих формувань. Тому розробка конкурентоздатної митно-логістичної системи для обслуговування зовнішньоторговельних вантажопотоків є одним з головних завдань відповідних державних та комерційних структур.* ***Мета.*** *Особливість виконання зростаючих обсягів експортних та транзитних перевезень вантажів полягає у необхідності залучення до організації зовнішньоторговельних поставок потужних транспортних вузлів із відповідним інфраструктурним забезпеченням. З урахуванням специфіки розвитку економічних інтеграційних процесів таким можливостям відповідають морські торговельні порти. А інтенсивне використання наявної та створення новітньої інфраструктури суб'єктів господарської діяльності вимагає розробки технологічних і структурних засад для удосконалення перевезень зовнішньоторговельних вантажів. У статті досліджується методологія формування інфраструктури митно-логістичних систем експортного спрямування з урахуванням оцінки конкурентоздатності транспортних послуг.* ***Результати.*** *Розробка та практичне використання методів формування виробничої інфраструктури в транспортних вузлах ґрунтуються на засадах економічної інтеграції та удосконалення перевізних процесів. З'ясовано, що для транспортних вузлів важливою характеристикою є дотримання термінів*

*накопичення та переробки імпортно-експортних вантажів. А із ускладненням завдань транспортного та митно-логістичного обслуговування виникає необхідність формування раціональної інфраструктури транспортних систем. Запропонована методологія формування інфраструктури транспортних вузлів дає можливість визначити шляхи інтенсивного використання наявних та створення перспективних виробничих потужностей митно-логістичних систем за умови оптимального розподілу матеріальних ресурсів. **Висновки.** В процесі проведення дослідження отримано нові результати для удосконалення методології формування митно-логістичної інфраструктури в транспортних вузлах. На підставі основних положень теорії системного аналізу отримано нові та доповнено наявні результати взаємодії окремих структурних елементів виробничих формувань міжнародного спрямування. Із використанням методу імітаційного моделювання розраховані інтегральні показники якісного транспортного обслуговування на прикладі експортних вантажопотоків. Проведене дослідження може бути корисним для підвищення ефективності транспортного обслуговування вантажопотоків у міжнародних виробничих структурах.*

Ключові слова: міжнародні перевезення, митно-логістична інфраструктура, транспортні системи, зовнішньоторговельні вантажі, транспортні вузли, економічна інтеграція.

Introduction. The formation of a rational structure of transport systems for the efficient servicing of foreign trade flows allows improving the competitiveness of existing production units by reducing the total logistics costs. In addition, with the use of technological and structural principles to improve transportation, it is possible to respond quickly to changes in seasonal supply volumes and the structure of logistics services. Compliance with these provisions, given the development of integration processes, becomes especially important for the production activities of powerful transport hubs and import-export enterprises, which store, process and tranship large volumes of foreign trade cargo. Diversification of transport system logistics services for a wide range of goods and the significant impact of market relations do not reduce the urgency of this problem, as the existing infrastructure is used by a significant number of business entities.

Formulation of the problem. Existing trends in the development of trade relations are based on the principles of economic integration between different countries and the relocation of production processes in international production structures. Due to the economic growth of countries, according to economic experts, the trends in the development of integration processes recorded in the recent period will continue for a long time. In recent years, the agro-industrial complex of Ukraine is increasing the volume of production and sales of agricultural products in domestic and foreign markets. Therefore, the organization of transportation of domestic agricultural products with the lowest costs for producers is one of the main tasks of the transport and road complex of Ukraine.

Analysis of recent research and publications. The methodology for determining the functional characteristics in the structures of transport and logistics formations is based on the use of the basic theoretical provisions of systems analysis [1; 2]. In

accordance with these prerequisites, the formation of the infrastructure of transport systems for servicing foreign trade flows is considered as an ordered set of sequential technological operations [2; 3]. In this case, the end result of one technological phase is the initial condition for another, and operational management of the whole complex of coordination of production processes in production structures is carried out on the principles of system integration [4; 5]. A number of scientific papers on the example of servicing import-export and transit cargo flows involving different modes of transport showed the feasibility and positive features of this approach [6; 7]. Some components of the transport and technological process in the customs and logistics structures are determined by the relevant indicators' characteristics of these production units [7; 8]. However, the very definition of integrated indicators of service of cargo flows allows us to conclude about the efficiency of the transport system as a whole [9; 10]. The development of trade relations on the basis of economic integration between states and individual economic entities has posed qualitatively new challenges to the country's transport system. In most cases, the beginning and end of the movement of foreign trade goods are carried out by various transport and logistics companies. And since the transport and technological process itself consists of a number of production operations of preparation, storage and warehousing of cargo, in the modern period it has become the basis of the approach to the creation of new customs and logistics systems [11]. Widespread use of logistics management methods is based on the use of technological and organizational principles to improve transportation by combining production, transport, warehousing and trade processes into a single production structure. And a fundamentally new approach to the development of integration processes involves the definition of organic relationships for the maintenance of material flows, including the integration of related financial and information processes into a single customs and logistics system [10; 12].

Formulation of the goals of the article. Existing tendencies to increase export and transit of agro-industrial products through the country outlined scientific prospects for developing technological and structural principles for improving grain transportation under intensive use of existing infrastructure of Ukraine's transport system, railway junctions and port facilities. Given the peculiarities of the implementation and growth of exports of grain, special attention should be paid to the organization of foreign trade supplies of these goods through sea trade ports.

Presentation of the main material. Under the condition of intensive use of the existing infrastructure of customs and logistics systems, uniform distribution of cargo flows and coordinated separate transport enterprises, sea trade ports of Ukraine are able to handle significant volumes of foreign trade cargo. Generalization of the technology of material flow movement on the example of grain resources allows determining the features of customs and logistics services of these cargo flows (Fig. 1).

The technology of transport service of grain traders is closely connected with the production activity of these economic structures. The functions of these organizations include the purchase and temporary storage of grain, the creation of a joint party and its delivery to the country of destination on chartered vessels. The above scheme of the export process requires quality transport services at all stages of its implementation.
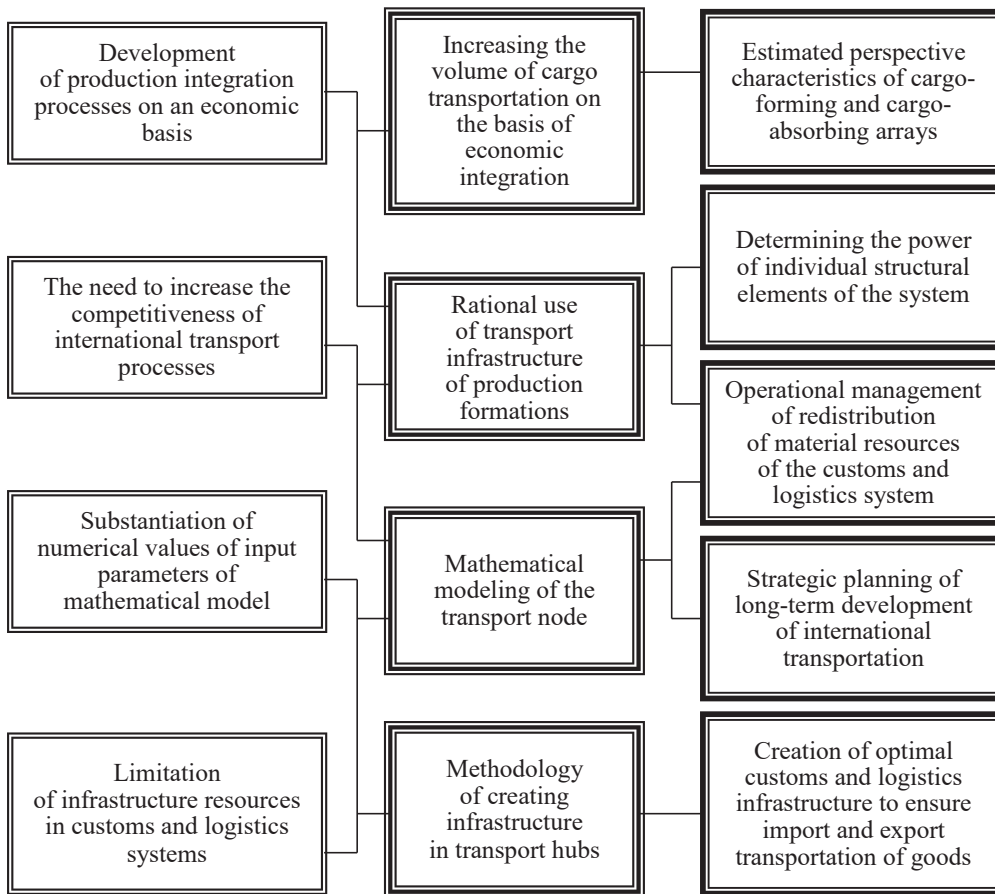
Development of production integration processes on an economic basis	Increasing the volume of cargo transportation on the basis of economic integration	Estimated perspective characteristics of cargo-forming and cargo-absorbing arrays
		Determining the power of individual structural elements of the system
The need to increase the competitiveness of international transport processes	Rational use of transport infrastructure of production formations	Operational management of redistribution of material resources of the customs and logistics system
Substantiation of numerical values of input parameters of mathematical model	Mathematical modeling of the transport node	Strategic planning of long-term development of international transportation
Limitation of infrastructure resources in customs and logistics systems	Methodology of creating infrastructure in transport hubs	Creation of optimal customs and logistics infrastructure to ensure import and export transportation of goods

Fig. 1. Determining the functional characteristics
of customs and logistics infrastructure in transport hubs

Determining the functional characteristics of the customs and logistics infrastructure requires a step-by-step analysis of the efficiency of the transportation process. The methodology of these studies at the first stage involves determining the optimization criteria. Such criteria for servicing these foreign trade flows can be summarized in logistics costs. Therefore, using the methodological principles of system analysis, each of the possible options for the movement of grain cargo is characterized by the specified integrated indicator F, provided the appropriate infrastructure.

Determining the technical and technological characteristics of the customs and logistics infrastructure under the condition of forming a joint batch of export and transit transportation of grain is considered on the basis of modern mathematical methods of optimization. To this end, the process of creating a combined party has been modelled as a valid set of a limited number of freight transport schemes. That is, the initial conditions assume that in the process of creating a joint export party in the transport hub can be implemented n production and technological processes $P_1, ..., P_n$ its accumulation. In this case, the appropriate infrastructure $R_1, ..., R_m$ is used, i. e. the existing transport system has b_i units of infrastructure elements R_i,

(i = 1, …, m). Then the amount of material and technical resources for the formation of a joint export party, performed under the transport scheme P_j is equal to a_{ij}, and the movement of one ton of cargo under the transport scheme P_j is characterized by the total cost of logistics services c_j.

Using these prerequisites, the formation of the infrastructure of transport systems is to determine the volume of transportation x_j for individual schemes P_j, $j = 1, …, n$, when the combined party minimizes the generalized logistical cost of moving a unit of output. Within the theory of systems analysis, such a problem is formally reduced to finding a vector $x = (x_1,...,x_n) \in E^n$, which minimizes the linear function

$$\min F(x) = c_1 x_1 + c_2 x_2 + ... + c_n x_n \tag{1}$$

and satisfies the system of restrictions

$$\left.\begin{cases} a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \left\{\leq,\geq,=\right\} b_1 \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \left\{\leq,\geq,=\right\} b_2 \\ \text{...} \\ a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n \left\{\leq,\geq,=\right\} b_m \end{cases}\right\} \tag{2}$$

$$x_1 \geq 0, \quad x_2 \geq 0, \quad x_n \geq 0 \tag{3}$$

The vector *x*, which characterizes the conditions for solving mathematical expressions (2) and (3) is considered an acceptable plan for the use of transport infrastructure, and their set defines a limited area *D* to solve the problem. Then the function *F(x)* is called the objective, and $x^* \in D$, which provides a minimum in it – the optimal plan for the formation of the infrastructure of the transport system. As a result of the calculations, the value of *F(x)* is considered to be the optimal solution of the objective function.

In the given mathematical dependences (1)–(3) the matrix of conditions and characterizes numerical values of the corresponding material resources a_{ij} of the separate scheme of movement of freights

$$A = \begin{Vmatrix} a_{11} & a_{12} & ... & a_{1n} \\ a_{21} & a_{22} & ... & a_{2n} \\ \text{........................} \\ a_{m1} & a_{m2} & ... & a_{mn} \end{Vmatrix}. \tag{4}$$

At the next stage of mathematical modelling, the efficiency of using certain elements of the customs and logistics system was analyzed. The peculiarity of this analysis is to determine the impact of the level of infrastructure on the resulting performance of the production system as a whole. The proposed methodology is focused on the substantiation of numerical parameters of individual structural elements of the transport and technological process in order to achieve the optimal end result. Appropriate coordination of actions of individual components of the customs and logistics system must be ensured. In addition, such production formations provide differentiated economic stability of independent structural units in the provision of transport services.

However, the technology of accumulation of a separate combined batch of grain cargo in the terminal has the feature that a number of similar operations are performed simultaneously in a separate transport hub. In the daily work with insufficient, and in some

cases the lack of appropriate infrastructure, it is not possible to use the best option for transport and technological scheme. Therefore, in mathematical models, the constraints of infrastructural resources b_i corresponding to the variable x_j are characterized by the values of the vector

$$B = \begin{Vmatrix} b_1 \\ b_2 \\ ... \\ b_m \end{Vmatrix}. \tag{5}$$

And in accordance with the chosen option of moving grain, each of the proposed technologies of accumulation is characterized by the corresponding cost of maintenance of the cargo flow. Therefore, the vector of total logistics costs of the corresponding transport scheme of transportation for the mathematical model (1) is written as

$$C = \begin{Vmatrix} c_1 \\ c_2 \\ ... \\ c_n \end{Vmatrix}. \tag{6}$$

As is known from the theory of optimization, in such cases the system of equations $A_x = b$ is compatible, and the maximum number of linearly independent vectors A_j, $j = 1, ..., n$ is equal to m. The final plan for the use of transport systems infrastructure was determined using the well-known Jordan-Gaussian exclusion method. Using the conditions of minimization of the objective function (1) and the matrix form of recording the limiting conditions (4)–(6) it becomes possible to conduct multivariate calculations to determine the priority areas for the formation of the appropriate infrastructure of customs and logistics systems.

As a result of generalization of a large number of possible schemes of movement of grain cargo flows it becomes possible to define the basic variants of use of an infrastructure of transport systems for creation of export party of cargoes. This technique has the advantages over the structure of the direct transport node, which allows for multivariate calculations of numerical values of the resulting indicators, considering the mutual influence of self-functioning elements. At the same time, such a scheme takes into account the peculiarities of the process of delivery of individual export consignments of grain, accumulation and temporary storage in stationary port elevators or watercraft. And the preliminary analysis of the existing options of transportation of grain with the involvement of different modes of transport and the using of elevator and warehousing enterprises gives grounds to differentiate the feasibility of using existing methods of delivery.

The total cost of logistics services for the maintenance of grain cargo flows in the export service is differentiated by the following components:
– services of grain-receiving enterprises;
– payment for transportation of goods by rail;
– additional railway transport services at the request of the customer;
– services of customs-licensed warehouses;
– services of port grain terminals or port elevators;

    – the cost of transhipment operations in the seaport by the direct method of work;
    – component of motor transport;
    – cost of transhipment operations by ship-loading machines of the grain terminal;
    – the cost of storing grain in cars on railway tracks;
    – payment for the use of railway freight cars;
    – payment under the terms of an additional agreement with the railway car service;
    – freight toll of the sea trade port.

The cost of basic and additional services related to technological operations at the elevator and warehousing enterprises consists of differentiated acceptance of grain cargo from vehicles, storage for a specified period of time, drying, cleaning and other operations to bring grain to a certain date and technical conditions of storage, shipment of grain cargoes for further transportation. It should be noted that the amount of payment for these services depends on the state of transport infrastructure of enterprises and the state of grain cargo. The methodology for determining the functional characteristics of the customs and logistics infrastructure in transport hubs is illustrated by the example of production activities of the Nikolayev sea trade port (Fig. 2).
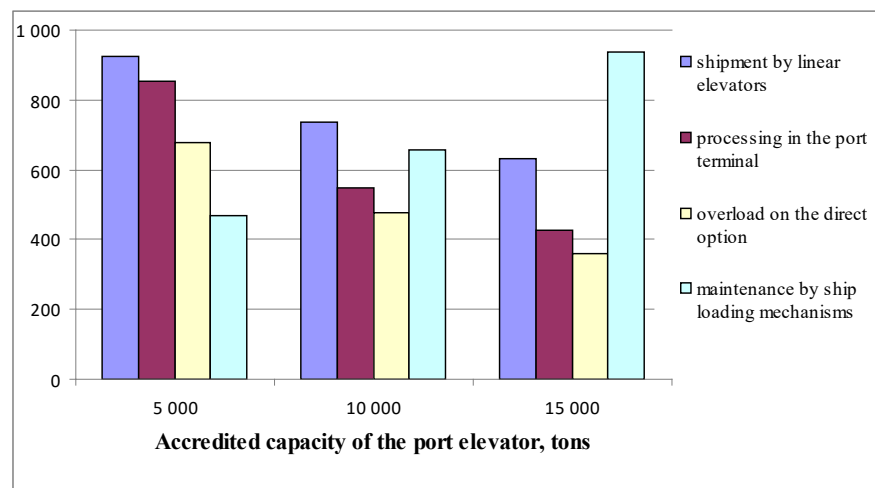
Fig. 2. Project daily productivity of the components
of the customs and logistics system under the condition of loading the export batch
of grain volume P = 15 000 tons for 7 days, tons/day

The change in the design daily productivity of individual components of the customs and logistics system in the proposed example is explained primarily by the limitation of the service life of the export batch of grain, and, accordingly, the need for prior accumulation of these goods. Under such circumstances, the share of the scheme of movement of grain cargo flows under the option "linear elevator – railway transport – port elevator – sea vessel" increases. And taking into account these circumstances, a significant part of the hopper railway cars, which were previously used for grain storage, is released. As a result, when increasing the accredited capacity of the port elevator from $H = 5$ thousand tons to $H = 15$ thousand tons, the cost of customs and logistics services decreases by 12.9 %.

The presence of accredited capacities in the port elevator has a positive effect on reducing the daily intensity of the use of railway transport infrastructure. This situation is explained by the fact that increasing the time of consolidation of the contracted consignment optimizes the daily number of vehicles on the routes. For example, increasing the capacity of the port elevator from $H = 5$ thousand tons to $H = 15$ thousand tons reduces the average daily amount of grain shipped by elevators by 31.6 %. And given the complexity of ordering free hopper cars during the period of intensive grain exports, the identified trend is positive.

As we know, one of the important elements of the infrastructure of international transport systems is the capacity of the port railway station. This situation is largely due to the limited capabilities of the general exhaust track and the large volume and range of goods in the export direction. However, increasing the capacity of the port elevator significantly reduces the amount of grain cargo arriving through the port railway terminal. Thus, the change in the accredited capacity from $H = 5$ thousand tons to $H = 15$ thousand tons leads to a decrease in freight traffic for the port terminal by 49.8 %.

Increasing the accredited capacity in the port elevator also has a positive effect on the transfer process under the direct option. In this case, the loaded car is removed by a gantry crane from the railway carts and fixed over the open hatches of the bilker. After opening the lower hatches of the railway car, the grain is poured into the hold of the vessel. With an increase in the accreditation capacity of the port elevator H by 5 thousand tons of grain overload in the direct option is reduced by an average of 23.6 %.

However, the availability of sufficient grain in the port significantly increases the load of stationary mechanisms. Thus, the increase in the capacity of the port elevator from $H = 5$ thousand tons to $H = 15$ thousand tons requires a doubling (from 468 tons/day to 938 tons/day) of the productivity of ship loading mechanisms.

Conditions for the creation and maintenance of export consignments of larger grain cargoes are characterized by the presence of the customs and logistics system of infrastructure elements of much greater capacity. Determining the functional characteristics of this system in the transport hub is considered on the example of consolidation and loading on the ship in the Odessa sea trade port of the export consignment of grain volume $P = 40$ thousand tons for 5 days. In this case, line and port elevators, customs terminals, as well as railway and road vehicles interact systematically. The peculiarity of servicing this export batch is also that, along with stationary storage facilities, closed railway hopper cars are actively used as a temporary option for a short period of time. For this purpose, the numerical values of the main functional characteristics of the system were determined and the ways of using the existing infrastructure in the transport node were analyzed (Table 1).

It is known that the consolidation and transhipment of a significant amount of cargo on a seagoing ship for a limited amount of time requires the mandatory use of powerful transport capabilities of rail transport. Therefore, the change in the capacity of the grain terminal D for processing railway cars plays a key role in determining the numerical values of individual components of the system. Thus, increasing the processing intensity of railway cars (from $D = 50$ cars/day to $D = 80$ cars/day) stimulates the storage of grain cargo in hopper cars. And since these operations are performed in advance, in the period of direct loading of grain on the ship, the intensity of its shipment from the elevators

is significantly reduced. Thus, increasing the service intensity from $D = 50$ cars/day to $D = 80$ cars/day makes it possible to reduce the daily volume of grain cargo from linear elevators by 1660 tons compared to 3120 tons at the initial stage.

Table 1

Project functional characteristics of customs and logistics infrastructure in the transport hub when servicing grain cargo flows of international orientation

Indexes	Capacity of the grain terminal for processing railway cars, cars/day						
	50	55	60	65	70	75	80
Daily shipment volume from linear elevators, tons	3120	2830	2550	2280	2010	1730	1460
Accredited capacity of the customs terminal, thousands of tons	11.22	13.39	15.56	17.73	19.90	22.08	24.26
The optimal number of vehicles with maximum capacity, units	75	67	60	54	49	45	42
Capacity of the port elevator, thousands of tons	15.35	13.83	12.42	11.10	9.87	8.70	7.62
Logistic cost of cargo flow maintenance, €/tons	37.63	36.68	35.76	34.93	34.17	33.48	32.86

At the same time, the growth of D within these limits requires for the agreed export party more than twice (from $B = 11.22$ thousand tons to $B = 24.26$ thousand tons) increase the accreditation capacity of the customs terminal. This situation is explained by the fact that these infrastructure elements are located, as a rule, at a relatively short distance ($l = 30–50$ km), so the delivery of grain cargo to the port berths is intensively performed by shunting locomotives in batches of 6–8 railway cars.

The active use of prompt delivery of these volumes of grain directly to the loading mechanisms of the port reduces the need for costly use of capacities H of the port elevator. The performed calculations show that if the indicator D changes within the specified limits, the numerical value of the indicator H decreases by 7.73 thousand tons and is 7.62 thousand tons under the condition $D = 80$ cars/day.

Consolidation of significant volumes of export cargo requires a separate description of the peculiarities of the use of vehicles. Despite the fact that due to the relatively high cost of transport work, this type of transport is used over relatively short distances ($l \leq 200$ km), heavy road trains E ($q = 20$ t) significantly replenish the volume of the consolidated party. However, along with the increase in the intensity of the use of railway transport, the daily number of vehicles decreases from $E = 75$ units to $E = 42$ units of rolling stock. As a result, the optimization of the existing infrastructure of the customs and logistics system made it possible to reduce the total logistics cost of servicing the grain cargo flow from $B = 37.63$ €/tons for $D = 50$ cars/day to $B = 32.86$ €/tons for $D = 80$ cars/day.

The described methodology of formation of the customs and logistics infrastructure of integrated systems provides an opportunity to determine ways to create promising production facilities in transport hubs. However, the practical application of this methodology is based on taking into account certain features of transport services of international cargo flows. In determining the functional characteristics of the customs

and logistics infrastructure of transport systems should takes into account the fact that the export of grain cargo is seasonal, and therefore performed, as a rule, from August to March next year. Therefore, in the inter-export period, part of the infrastructure elements is involved in other technological processes, and the other part of the port infrastructure is in forced downtime. This production situation should be taken into account when calculating the costs associated with the forced maintenance of a significant part of the specialized infrastructure of the transport hub.

Conclusions. In the process of conducting a study of the development of integration processes in the system of servicing export cargo flows, new results were obtained to improve the methodology for forming the customs and logistics infrastructure of transport hubs. On the basis of the basic provisions of the theory of the system analysis regularities of interaction of separate structural elements of industrial formations of the international direction are defined. It is established that when increasing the accreditation capacity of the port elevator by $\Delta H = 10$ thousand tons, the generalized logistics costs F decrease by 4.73 €/tons. The peculiarity of the results is that they take into account the possibility of using alternative methods of consolidation, storage and transhipment.

It is shown how the influencing factors takes into account the peculiarities of the implementation of the necessary technological processes by different modes of transport. The obtained result of the reduction of the generalized logistical cost F in the maintenance of grain freight flows in transport hubs takes into account the increase in the intensity of the use of railway cars and the intensity of the use of other infrastructure elements.

It is determined how the functional characteristics of the customs and logistics infrastructure in transport systems affect the efficiency of freight traffic in international traffic. However, when calculating, in addition to the impact of resource provision of international transport, it is necessary to take into account the peculiarities of servicing cargo flows by different modes of transport, seasonality of grain transportation and characteristics of existing and promising consumer markets.

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