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THE ECONOMIC CRISIS AS A FACTOR IN CHANGING THE STRUCTURE OF MULTIMODAL TRANSPORTATION ROUTES

Abstract. The article deals with the problem of assessing the impact of the economic crisis as a factor of the necessity for systemic change in the structure of multimodal transportation routes. The impact of the economic crisis, in terms of crisis theory and the crisis as an ontic category, is considered by the authors as a driving factor in changing the paradigm of the system of multimodal transportation. Therefore, the task of quantitative assessment of the impact of the economic crisis for intra-system assessment of the need for qualitative change in the structure of cargo transportation routes, first of all, their most vulnerable type - multimodal transportation, becomes especially important. The authors contrasted the existing methodology of traffic optimization with a mathematical formalization based on crisis theory and graph theory. This allowed a mathematically correct analysis of existing challenges in real time and, accordingly, to propose changes in the structure of multimodal transportation routes so that these changes minimize the impact of existing risks. This approach will prevent the formation of traffic jams on transport routes and nodes of the transport system and, accordingly, the collapse of freight traffic. Avoiding the collapse of traffic, in turn, will prevent it from extremely negative social, political, economic consequences for the country. The analysis confirmed the spontaneous formation of traffic flows that are alternative to the existing ones in the event of an increase in the level of threats. The spontaneous nature of the formation of the new transportation structure has not yet led to the collapse of the transport system due to the availability of resources of the transport network and a significant reserve of design capacity of transit transport hubs — seaports. But if the level of threats increases to more transport routes, the likelihood of collapse will increase. Therefore, the authors came to the conclusion that: 1) a permanent forecast of the level of risks is required; 2) assessment of the impact of the crisis on the transport system is necessary; 3) only centralized management of changes in the structure of

transportation routes, in particular, multimodal ones will allow to minimize the impact of the crisis and avoid the risk of collapse of the transport system.

Keywords: economic crisis, risks, multimodal transportation, mathematical modeling, change of route system.

JEL Classification O3, Q43, P5

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ЕКОНОМІЧНА КРИЗА ЯК ФАКТОР ЗМІНИ СТРУКТУРИ МАРШРУТІВ МУЛЬТИМОДАЛЬНИХ ПЕРЕВЕЗЕНЬ

Анотація. Присвячено проблемі оцінки впливу економічної кризи як чинника необхідності системної зміни структури маршрутів мультимодальних перевезень. Вплив економічної кризи з погляду теорії криз і кризи як онтичної категорії розглядається як рушійний фактор зміни парадигми системи мультимодальних перевезень. Тому завдання кількісної оцінки впливу економічної кризи для внутрісистемного оцінювання необхідності якісної зміни структури маршрутів транспортування вантажів, передусім найбільш вразливого їхнього виду — мультимодальних перевезень, набуває особливого значення. Протиставлено існуючій методології оптимізації перевезень математичну формалізацію, яка базується на теорії кризи і теорії графів. Це дозволило математично коректним чином проводити аналіз у реальному часі наявних викликів і, відповідно, пропонувати зміни у структурі маршрутів мультимодальних перевезень таким чином, щоб за вказаних змін було мінімізовано вплив наявних ризиків. Вказаний підхід заводить утворенню на транспортних шляхах та у вузлах транспортної системи traffic jams і, відповідно, колапсу перевезень вантажів. Уникнення колапсу перевезень, у свою чергу, заводить його вкрай негативним соціальним, політичним, економічним наслідком для країни. Проведеним аналізом підтверджено факт стихійного формування альтернативних наявних транспортних потоків у разі зростання рівня загроз. Стихійний характер формування нової структури перевезень

поки що не призвів до колапсу транспортної системи у зв'язку з наявністю ресурсів пропускної здатності транспортної мережі та значного резерву проєктної потужності транзитних транспортних вузлів — морських портів. Але за збільшення рівня загроз для більшої кількості транспортних шляхів імовірність настання колапсу збільшиться. Тому автори дійшли висновку, що: 1) потрібний перманентний прогноз рівня ризиків; 2) необхідна оцінка впливу кризи на транспортну систему; 3) лише централізоване керування зміною структури маршрутів перевезень, зокрема мультимодальних, дозволить мінімізувати вплив кризи, уникнути ризику колапсу транспортної системи.

Ключові слова: економічна криза, ризики, мультимодальні перевезення, математичне моделювання, зміна системи маршрутів.

Формул: 1; рис.: 1; табл.: 2; бібл.: 20.

Introduction. Multimodal transportation is an effective modern type of transportation, which uses different types of transport at different stages of the route, but, at the same time, the cargo has a single end-to-end information support. This greatly simplifies bureaucratic procedures for re-registration of transit cargo, digital supervision and control over the passage of goods along the route and, thus, reduces the cost and speeds up the transportation process [1]. Multimodal Freight Transport (MMFT) requires staff that is thoroughly familiar with digital media and promotes the introduction of new technologies [2] the same time, by all indications, multimodal transport is the most sensitive to the significant level of impacts of the crisis. It is widely known that the transport network is an integral part not only of the economy of the modern world, but has long been a key means of providing the population with everything that is necessary for life. Therefore, it is the primary target of attack for terrorist, subversive groups, modern means of warfare [3], the target of other modern manifestations of the crisis.

The impact of the crisis, from the point of view of crisis theory and as an ontic category, which is known to be characterized by the concepts of quantitative, extensive, intrasystemic, objective and essential, is considered by us as a driving factor changing the paradigm of the MMFT system. According to this definition, the quantitative assessment of the impact of the crisis for the intra-system assessment of the need for a qualitative change in the structure of the routes of the MMFT is of particular importance.

The impact of the crisis can be assessed through changes in the level of differences [4], in particular, the risks of active hostilities, terrorist attacks, sabotage, etc., which [5] are called «absorbing», i.e. risks that may exceed the total weight of other types of risks. That is, this impact will not be uniform for all MMFT transit points, which, in fact, are now all seaports in Ukraine. This will inevitably lead to a change in cargo flows between these ports. In a spontaneous nature, the change in freight flows can lead to traffic jams and, consequently, the collapse of the transport system. The tool that will help this is the information and organizational means of counteraction, detailed elaboration of scenarios of probable variants of the transport crisis with the subsequent simplification of the implementation of the management system of change of freight flows in real time. The urgency of the need for real-time modeling is that events may not follow prepared scenarios, but develop in an unexpected way. And this, in turn, requires the use of specialized information forecasting tools based on a mathematical model that is able to generate relevant forecasts.

In the previous works of the authors [5—7] some variants of mathematical forecasting were developed on this topic. Unfortunately, these options are not adapted for operational use, as they require significant computer resources and large resources for calculations. Therefore, the task of forming such a mathematical formalization that will meet the challenges of the crisis arose.

Analysis of research and problem statement. In the scientific literature, minimizing transportation risks is often seen as an optimization task. Thus, the paper [8] considers an adaptive integrated system that uses simulation models and the principle of metamodeling. The work [9] is devoted to optimization of multimodal transport networks. In this paper, it is proposed to apply

a mathematical model, which consists in dynamic balancing using the principle of user equilibrium. As a result, this model should minimize generalized user costs.

In [10] applies a synergistic systems approach to containerized multimodal transport logistics with a combined integrated analysis of four subsystems: equipment, management, business operations and information interaction. In [11] uses competency analysis to form a mathematical model. In [12] solves the problem of optimizing multimodal transport in terms of the best use of the transportation means and in accordance with its proper utilization on the entire transport route under the conditions of transit unloading / loading of the transportation means.

This indicates that in the above research, each scientist sees the problem of minimizing specific risks, optimizing MMFT from a somewhat narrow, utilitarian, rather than systemic point of view.

As the analysis shows, the risks of MMFT depend on different parameters: deterministic, probable, fuzzy. The objective functions that the carrier can control may also be different: the cost of transportation, transportation time, the degree of security of the goods, and so on. Regarding the deterministic and probabilistic parameters of transportation — there is a sufficient set of proven methods of their consideration.

As for fuzzy methods, there are different views and scientific approaches. In [13], for example, proposed an improved ARAS methodology for interval estimation of the intuitionistic fuzzy continuum of variables for transport chain modeling. In [14] also uses the ARAS methodology but relies on the fuzzy impact factor for the corresponding interval estimates. In [15] addresses the problem of multicriteria decision making for the use of fuzzy additive ratio estimation (FARAS), i.e. the use of the continuum of fuzzy variables in decision making for reverse logistics problems. Approaches to solving problems with many criteria are also available in [16] — a model of evaluation using fuzzy sets, an approach with several criteria, in [17] proposes an approach to solving multi-purpose optimization problems, in [18] studies offering advantages in optimization problems with several criteria.

Unsolved aspects of the problem. Unfortunately, as the analysis shows, mathematical modeling using these approaches in the case of significant uncertainty gives an insufficiently relevant result. In addition, the scientific literature still does not pay attention to the crisis as an intrasystem category and its impact as a quantitative factor for a qualitative change in the structure of transportation.

The purpose of the article is to assess the impact of the economic crisis as a factor of the necessity for systemic change in the structure of multimodal transportation routes.

Research results. Crisis theory and graph theory were chosen as the main mathematical apparatus for modeling by the authors. The graph of the transport system of transportations of Ukraine and transport connections with the neighbouring countries is formed on the general space of variables Q . Transport nodes are considered as nodes of the graph, transport paths — as its edges. Obviously, for each of the edges there is a corresponding limit value of capacity — the number of loads per unit time g_τ , which will be called the weight of the edge. For the main transport hubs of export and import transportation of Ukraine, seaports, there is an indicator — the design capacity of port G . This indicator is the technological limit beyond which the risks of traffic jams increase significantly. Of course, reconstructions, improvements, completions can lead to a certain increase in this indicator, which should lead to a documented change.

From the point of view of mathematical formalization, any channel (type of transport, transport highway, etc.) is connected with the seaport, as a node of the graph of the transport system of Ukraine can not have a capacity greater than specified, i.e.: $g_\tau^i \geq G$, because $g_\tau^i \in \{g_\tau^1, g_\tau^2, g_\tau^3 \dots\}$. Obviously also, $f: G \rightarrow g_\tau$. The probable increase in the number of loads greater than the limiting weight of the edge g_τ^i is the mathematical formalization of the sign of probable collapse.

In this case there are two main options to avoid collapse — it is redirection of cargo to areas with a lower level of threat, which are not yet congested (or for less important goods to areas with a higher level of threat) and new alternative routes, such as transit points of neighboring countries,

bypassing dangerous areas (this will require interstate coordination and prior contractual agreement). In this case, there is an intermediate task to find the appropriate risk limits for the respective types of cargo with the subsequent use of the methods of graph theory tested in previous works [5—7].

But according to this problem statement the objective function, in contrast to the traditional tasks of MMFT optimization, will not be the cost or time of transportation, but the safety of cargo transportation. The criterion for the appropriate level of transport safety is the achievement of the challenges and risks of the bifurcation point. Reaching the bifurcation point will be a sign of the need to implement a different structure of multimodal transportation routes.

The proposed algorithm is as follows. Let us denote the objective function of maximum transport safety by strictly maximum safety, respectively $f^{\max}$, $f^{st. \max}$. We denote as f^* , $f^{st.*}$ the functions that are, respectively, the closest to $f^{\max}$ and strictly the closest to $f^{\max}$ on the corresponding set of variables. Each of these levels of approach to the value of $f^{\max}$ is a criterion for decision making.

For simultaneous use of deterministic, probability and fuzzy factors of influence we allocate on the general space of variables Q subspaces of the specified factors on which we define the specified safety intervals. In accordance with the proposed algorithm, we form a three-dimensional response surface at, respectively, deterministic, probability and fuzzy coordinates and find the coordinate limits $f^{\max}$, $f^{st. \max}$, f^* , $f^{st.*}$.

Next, we determine the interval of change of the objective function $f \in (f^{\min}, f^{\max})$. We consider the value of $f^{\min}$ from the point of view of crisis theory as a mathematically defined crisis (bifurcation point).

$$f^{\min} = \gamma(\delta^{\max}) \leq \theta_i,$$

where $\delta^{\max}$ is the maximum level of risk as a decision factor; θ_i is the design capacity of the i -th port as a transport hub.

The level of risk as a decision factor $\delta^{\max}$ is taken expertly. Moreover, in fact, the level of decision-making may be different — from public to corporate. In the case of the corporate level of decision-making, it is important that the total volume of traffic of all corporate carriers, which is formed spontaneously, through a certain channel was greater than the above indicators G and θ_i .

As the analysis shows, this reaction of carriers has already taken place with the increase in the level of military threats with the beginning of the intensive phase of hostilities in eastern Ukraine in 2014—2015. This led to a redistribution of transit cargo flows through the ports of Ukraine (Table 1, Fig.). In this case, we consider the transit cargo available in the statistical reporting [19; 20], due to the lack of separation of statistical institutions of multimodal transport as a separate type of cargo, because transit cargo is purely multimodal transportations, in contrast to other types of cargo (dry cargo, bulk cargo, etc.), which may or may not have multimodal features.

The analysis was performed using statistical data [19; 20].

Table 1

Dynamics of transit cargo transportation through seaports, thousand tons

Years	1	2	3	4	5	6	7
2012	72.30	3.95	1635.57	40.80	29.50	190.51	9362.02
2013	23.10	8.88	1217.51	75.98	172.45	186.61	7794.18
2014	14.90	3.03	473.60	4.70	577.60	127.09	6434.66
2015	0.00	0.00	8.30	0.00	742.64	55.82	5214.83
2016	0.00	0.00	0.00	2.10	225.43	17.73	3537.62
2017	0.00	0.00	0.00	0.00	251.43	0.00	4788.40
2018	0.00	0.00	0.00	0.00	48.84	0.00	5552.19
2019	0.00	0.00	0.00	0.00	7.06	0.00	6938.84
2020	0.00	0.00	0.00	0.00	64.2	0.00	6476.9

Notes. Ports: 1 — Berdiansk, 2 — Bilhorod-Dnistrovsk, 3 — Mariupol, 4 — Olviia, 5 — Kherson, 6 — Pivdennyi.

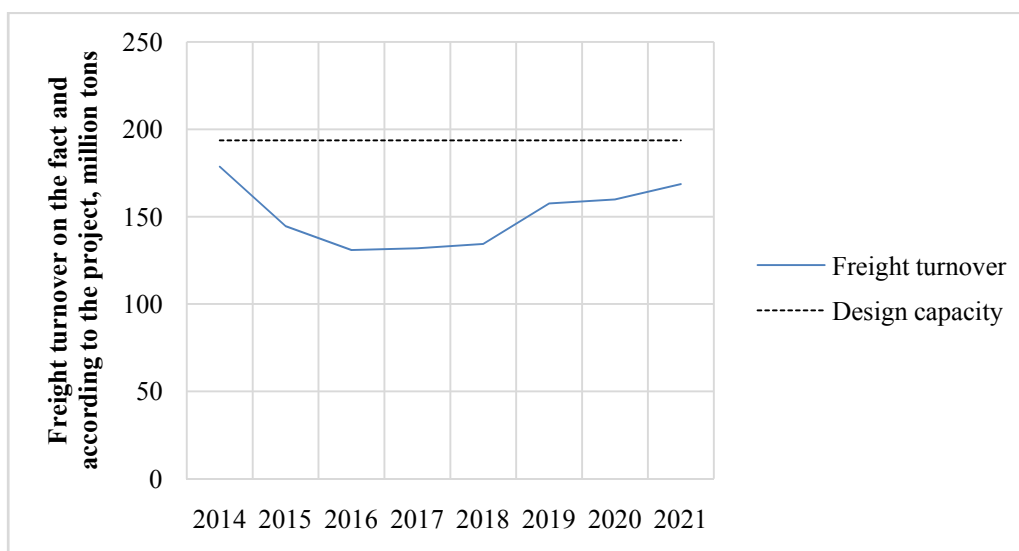


Fig. Total freight turnover on the fact and according to the project, million tons

As shown by the analysis of the data of *Table 1* through the most endangered ports — Berdiansk, Bilhorod-Dnistrovsk, Mariupol, Olviia transit cargo flows have stopped (or almost stopped) when the level of threat reached unacceptable value since 2015. Through the port of Kherson and Olviia, transit cargo flows decreased with a small lag in time and, also with a certain lag in time, the transit cargo flow through the port of Pivdennyi increased (see *Table 1*).

This is due to the fact that for the port of Pivdennyi the absorbing risk of hostilities was much lower than for the above ports and corresponded to the average level of this risk in the country [6]. Therefore, transit traffic for it was appropriate from the point of view of corporate carriers.

A comparative analysis of the degree of port congestion (*Table 2*) and the integral value between the cargo turnover and the design capacity of the ports (see *Fig.*) indicates that the cargo flows of MMFT did not acquire critical value during this time. That is, the spontaneous attempt of carriers to reduce the risks of transportation using other routes did not reach the level of collapse, because the system had significant capacity reserves, and the threat was significant only for the ports in the east. But, as the analysis shows, with the increase in the level of threats to most of the transport network, in particular, transport hubs, a collapse situation will be inevitable without the introduction of sound management.

Table 2

Cargo turnover of seaports of Ukraine, million tons

Ports	Years							The degree of port congestion
	2014	2015	2016	2017	2018	2019	2020	
Odesa	40	25.6	25.3	24.1	21.7	25.34	23.37	0.64
Chornomorsk	32	17.3	15.9	17.2	21.5	26.15	23.88	0.82
Mariupol	20	8.98	7.6	6.15	5.88	6.48	7.03	0.45
Mykolaiv	21	22.2	22.4	23.5	29.2	33.14	33.13	0.78
Reni	14.5	0.9	0.97	1.12	1.32	1.27	0.78	0.09
Bilhorod-Dnistrovskyi	1	0.71	0.48	0.35	0.24	0.12	0.075	0.71
Berdiansk	3.7	4.45	3.08	2.39	1.18	0.001	0.001	0.12
Izmail	8.5	4.82	5.68	5.1	4.7	4.28	3.24	0.67
Oktiabrsk	3	6.9	6.5	6.8	2.9	3.097	3.91	0.23
Skadovsk	1	0.04	0.03	0.02	0.01	0.01	0.004	0.04
Ust-Dunaisk	4	0.02	0.02	0.05	0.05	0.07	0.02	0.01
Kherson	5	4.13	3.71	3.3	3.1	3.8	2.85	0.20
Pivdennyi	40	48.6	39.3	41.9	42.7	53.86	61.66	0.81
On all ports	193.7	144.65	130.97	131.98	134.48	157.61	159.95	0.84

According to the specified algorithm and the corresponding level of threat the indicator of actual cargo turnover for 2021 is forecasted. That is, the use of the proposed model for a certain level of threats to generate predictive values is practically implemented.

Conclusions. In the proposed article, the authors consider the response to the crisis of the existing technological — transport system using the example of the most modern type of transportation — multimodal transportation of goods, which is the most sensitive to the challenges of the crisis by its characteristics.

The proposed approach is opposed to the classical approach of utilitarian optimization. This approach is based on crisis theory and the interpretation of the crisis as an ontic category. Since the ontic category is characterized by the concepts of quantitative, extensive, intrasystem, objective and essential, it, by definition, can serve as a methodological basis for building a mathematical model and be considered as a driving factor in changing the paradigm of the MMFT system.

This allows to form not spontaneous, but conscious, managed, rational resistance to the crisis and minimization of possible threats to prevent the collapse of the transport system.

The challenges of the crisis, as the analysis showed, are already large enough, and the spontaneous response to them did not lead to the collapse of the transport system only because the resources of routes and design capacity reserves of transit points of the transport network were sufficient to absorb spontaneous traffic flows. Obviously, when most of the transport network is affected by the crisis, it will be impossible to avoid collapse without organized counteraction.

To prevent this, the use of the proposed model requires the implementation of permanent forecasting of the level of risks. According to the obtained forecast values, it is necessary to assess the impact of the crisis on the transport system and, in accordance with the results of this assessment, implement centralized management of changes in the structure of transportation routes, which will minimize the impact of the crisis and allow to avoid systemic social, political and economic threats.

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