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MODEL OF OPTIMIZATION OF THE PARAMETERS OF THE DELIVERY PROCESS IN INTERNATIONAL TRAFFIC

Summary. The efficiency of border crossing services depends on a number of parameters, including the scope of control activities, the number of vehicles to be serviced and the human resources involved. The paper presents the mathematical model allowing the optimization of service parameters at the border crossing point. The queuing theory was implemented due to unbalanced nature of processes.

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Scientific interest of the model relates to the optimization of the parameters in international goods delivery under the conditions of random nature of vehicles arrival, and with the uneven intensity of servicing vehicles by state administrative services at the crossing border. The model takes into account the trade-off between the number of border staff and vehicle handling time. As a result of the application of the model, the handling process at the border crossing can be optimized, which will lead to a reduction of delivery costs in international traffic.

Keywords: simulation model, process parameters, international freight, border crossing

1. INTRODUCTION

The rapid economic development of countries, together with the integration process in Europe, is leading to an intensification of international relations and an increase in the volume of trade and, as a result, to an increase in the volume of goods, which is contributing to the development of the transport sector. Transport has a prominent place in the implementation of trade agreements. Its poor organization can lead to negative effects on the trade transaction execution. An incorrect choice of transport, route, packing, and transportation mode can reduce the quality of the services. The result of deficiencies and mistakes is the deterioration of the company's image. The combination of the low level of organization of the delivery of goods raises doubts in the international community as to the appropriateness of using the services of the carriers of a given country, and after all, contributes to the decline in the transport sector's revenues.

In arranging the delivery of goods, consignors, intermediaries, freight forwarders, carriers, customs officers, insurers, and representatives of other organizations enter into complex relationships, which are determined by economic processes, environmental, political and social factors. In such a constantly changing environment, with a high level of competition in the transport services market, it is necessary to search for rational transport routes [1], appropriate technological delivery schemes [2], introduce innovative forms and methods of organization of the transport process, and improve existing and develop new promising transport technologies. The solution of complex tasks requires constant study of issues of ensuring, regulating, and improving the delivery of goods.

2. LITERATURE REVIEW

The efficient operation of the logistics system is crucial for various industries and has a direct impact on the economic development of society [3]. Supply chains are formed with the aim of reducing shipping costs, reducing transport time and improving the efficiency of the logistics system in the long term.

In [4] it was stated that the functioning of the logistics system in a dynamic environment is related to many problematic situations.

In today's global market, competition is not between companies, but between supply chains. The best supply chain is determined by comparing supply chain performance indicators. The most efficient supply chains operate over a long period of time. The efficiency of the supply chain is influenced by various internal and external factors. The optimal selection of the parameters of these factors increases the efficiency of the supply chain [5].

At present, the increasing importance of energy issues, rational use of resources and sustainable development offer great opportunities for the formation of the supply chain. An optimal supply chain structure is vital to the success of the industry now more than ever [6].

Supply chain management uses various optimization techniques to improve the efficiency of the process. To optimize supply chain networks, mathematical modeling [7], simulation modeling [8], as well as stochastic optimization [9] can be applied.

Supply chain costs constitute a significant proportion of the cost of the final product. Therefore, it is necessary to minimize the costs of the supply chain, which will increase the efficiency of the delivery process and will contribute to higher profits. At the same time, supply chain operations are random in nature, which affects their execution time and, in general, costs. This necessitates the optimization of supply chain parameters. In turn, the minimization of supply chain costs will make it possible to form compromise technological solutions at all stages of the goods delivery process.

The values of technological parameters of the supply chain affect its effectiveness in the process of managing the movement of goods between individual links in the chain [10]. These parameters can be taken into account in the mathematical model as decision variables to determine their best combination in the optimization process.

Researchers [11] consider the problem of supply chain design, which is solved using a linear programming model with mixed integers. The model optimizes various demand scenarios, and the results obtained are important for designing a supply chain with stochastic parameters. Thus, when designing a supply chain, it is necessary to assess the changing demand for products and take consider stochastic parameters.

To solve the problem of optimal supply chain management, a methodology based on reliable optimization under the condition of stochastic demand in discrete time is proposed [12]. The proposed approach includes a wide range of phenomena and requirements, and also takes into account the capacity of echelons and links.

In [13], a predictive stochastic gradient method was proposed to improve the efficiency of supply chain management. In DOI:ng so, the focus is on developing an efficient multi-stage supply chain using factors such as cost, time, and risk.

In developing mathematical models that describe the state of the transport market, a logistics approach is needed, based on a clear interaction of demand, supply, production, transport, and distribution of products to achieve the greatest effect [14].

The essence of the logistics concept is the development of a system for the management of material [15,16] and related information [17], based on logistical principles and methods [18].

High efficiency in the use of methods and models in logistics will be achieved if several conditions are met, among which [19,20]:

– systemic approach to the problem at hand,
– scientific validity of the approaches and models themselves,
– adequacy of models for the real system, the objective consideration of subsystem interrelationships,
– continuity of the model implementation process.

The reliability of the logistics system is largely determined by the smooth operation of the transport network and infrastructure [21-23]. The efficiency of technically sound transport services depends mainly on the level of organization and management [24,25]. Road transport management is aimed at facilitating the delivery of goods by road from suppliers to customers, as well as reducing freight costs and increasing profits.

In the conditions of development of Industry 4.0 introduction and use of informational, digital and innovative intelligent technologies in modern transport systems and supply chains is necessary [26,27].

The results of the research [28] demonstrated that several enabling technologies such as wireless communication technology, sensors, positioning technology, and web-based platforms are widely used in international freight transport.

The process of organizing the delivery of cargo "just in time" requires a quantitative assessment of the transportation process and its components.

Thus, efficient supply chain management is able to ensure permanent competitive advantages of international transportation. Ensuring effective management of supply chains determines the need to create new models of optimization of logistics operations and the organization of interaction and partnership in all links of the logistics system. At the same time, the stochasticity of certain technological processes, the random nature of the demand for transport services and the dynamism of the external environment should be taken into account.

3. PROBLEM STATEMENT

The purpose of this publication is to select rational technological parameters of the logistic chain of delivery of goods to improve its functioning. The solution to this problem will be to minimize the cost of delivering goods in international trade, taking into account the factor of delivery of goods "exactly on time".

The crossing point is a complex system consisting of separate elements (subsystems), each of which performs certain functions in the technological process of crossing the state border.

The permit technology determines the types, sequence, content of control operations, and the procedure for the passage of persons, vehicles, goods, and other property across the border.

The mathematical model of goods supply in international traffic takes into account the specificity of European Union Eastern border, namely Ukrainian border crossing point, but it can also be used to optimize the functioning of other nodes in the international traffic.

4. SELECTION OF TECHNOLOGICAL PARAMETERS OF THE DISTRIBUTION CHANNELS IN INTERNATIONAL TRAFFIC

Crossing the border by people, vehicles and cargo across the border between Poland and Ukraine is carried out after border and customs control, and, in appropriate cases, also sanitary, environmental, veterinary or phytosanitary control or control related to the export of cultural property from the territory of Ukraine.

For a system as unbalanced as a border crossing point, the queuing theory apparatus was applied.

The queuing system makes it possible to assess the quality of the service system’s functioning under the conditions of service queues and the uneven nature of the service itself, and will allow for better management of the processes at the crossing point.

This makes it possible to determine the optimum value of the performance characteristics of the service system.

The main elements of a queuing system are as follows:

- structural indicator of the class and type of queuing system,
- traffic flow at the crossing point,

– service flow.

The functioning of any queuing system can be represented through all possible states and the intensity of transition from one state to another. The basic parameters of the operation of a queuing system are the probability of its condition, i.e., the possibility of a request in the system –P_n. Probability P_0 describes the condition when the system is free of requests and the service line is idle.

The intensity of one request is also an important parameter for the operation of a queuing system λ, That is, income per unit of time, the intensity of service μ.

To study the structure of the input flow of primary statistics, the random time interval between two vehicle arrivals at a crossing point is considered. The random nature of the input results in a queue at some points at the input to the system.

In this case, the rate of service requests is defined as the inverse value of the time interval between incoming vehicles t_{avt}:

$$\lambda = \frac{1}{t_{avt}} \tag{1}$$

Service intensity is defined as the inverse value of the processing time for a single request t_{serv}:

$$\mu = \frac{1}{t_{serv}} \tag{2}$$

After conducting statistical surveys (the sample size is 500 values), it is determined that the input flow of vehicles is distributed according to the indicative law.

Given the lack of analytical dependencies for this type of queuing system, a corresponding graph model of a three-phase queuing system has been developed.

The Kolmogorov system of equations defines a quadratic matrix. Changing one of the equations to a normalization condition$\sum_i \sum_j \sum_k \sum_l P_{ijke} = 1$, define all state probabilities P_{ijke}. through the odds P_{ijke} the technological parameters of the given system are defined.

A mathematical model of the choice of rational technological parameters in international traffic has been developed as a result of the analysis of the delivery technology in international traffic and the studies carried out.

The mathematical model is as follows:

$$\begin{gathered} R(\mu 1, \mu 2, \mu 3) = C_{\mathrm{vc}}^{\mathrm{lo}} \cdot \frac{Q}{qlo} + \frac{qlo \cdot A \cdot K_{\mathrm{lo}}}{qclm \cdot h} + T1 \cdot L1 + \\ + C_{mc1} \cdot \frac{\mu 1}{Wp_1} + C_{mc2} \cdot \frac{\mu 2}{Wp_2} + C_{mc3} \cdot \frac{\mu 3}{Wp_3} + C_{pr}^{dk} \cdot \left[\frac{1}{\mu 1} \cdot (P_4 + P_{11}) + \right. \\ + \frac{1}{\mu 2} \cdot (P_8 + P_{14}) \left(\frac{2}{\mu 1} + \frac{1}{\mu 1}\right) \cdot (P_8 + P_{13}) + \frac{3}{\mu 2} \cdot (P_{13} + P_{17} + P_{18}) \\ \left. + \left(\frac{3}{\mu 1} + \frac{2}{\mu 2}\right) \cdot (P_{12} + P_{16}) + \left(\frac{4}{\mu 1} + \frac{3}{\mu 2}\right) \cdot P_{19} + \frac{1}{\mu 1} + \frac{1}{\mu 2} + \frac{1}{\mu 3}\right] + \\ + T2 \cdot L2 \to min \end{gathered} \tag{3}$$

where qlo — capacity of the loading point, t/hour; C_{vc}^{lo} − value of vehicles standing idle during loading, UAH / hour; K_{lo} − the cost of the handling equipment, UAH; Q − consignment, tone; h − consignor’s production capacity, t/year; q_{clm} − capacity of one loading mechanism, t/hour; A − depreciation expenses; $T1$ − tariff for freight on the territory of Ukraine, UAH/km; $L1$ − distance of transport on the territory of Ukraine, km; C_{pr}^{dk} − cost of waiting hour during border crossing, UAH/hour; $C_{mc\,i}$ – maintenance crew cost, UAH/hour; μ_i – intensity of service in the i-th element, units/hour; Wp_i – productivity of one person in the i-th element, units / hour; $1, n$ – the number of control elements at the state border; $T2$ – tariff for cargo transportation outside the territory of Ukraine, UAH/km; $L2$ – distance of transportation outside the territory of Ukraine, km.

The model has two constraints:

1. Carrying capacity of vehicle of 20 t.
2. The limitation system generic parameter is:

$$\mathrm{T}_{ctt} < \mathrm{T}_{con} \tag{4}$$

where T_{con} – contract time; T_{ctt} – vehicle travel time.

$$\mathrm{T}_{ctt} = t_{lo} + t_{\mu o\varpi 1} + t_{sb} + t_{\mu o\varpi 2} \tag{5}$$

where t_{lo} – load time; t_{mov1} – time of vehicle movement to the border of Ukraine; t_{sb} – time of crossing the state border; t_{mov2} – travel time to destination.

The loading time shall be determined as follows:

$$t_{lo} = \frac{Q}{qlo} \tag{6}$$

The time taken to reach the Ukrainian border is calculated as follows:

$$t_{mov1} = \frac{L1}{V_T} \tag{7}$$

The time for crossing the state border is determined by the formula 16.

Time to destination:

$$t_{mov2} = \frac{L2}{V_T} \tag{8}$$

Thus, the mathematical model allows finding optimal technological parameters of the logistic chain of delivery of goods in international traffic, namely:

– costs of the entire international supply chain R,
– intensity of service at customs control μ_1,
– intensity of service during border control μ_2,
– intensity of service during other types of state control μ_3 (customs control, border control, sanitary, environmental, veterinary, phytosanitary control, control related to the export of cultural property from the territory of Ukraine).

Through probabilities, the following calculation parameters can be derived from a queuing system, allowing a more detailed analysis of the functioning of the logistics chain.

Relative throughput is defined by:

$$q = 1 - (P_{16} + P_{17} + P_{18} + P_{19}) \tag{9}$$

Absolute bandwidth:

$$A = \lambda \cdot q \tag{10}$$

The average number of vehicles in the queue:

$$\bar{r} = (P_4 + P_9 + P_{11} + P_{14}) + 2 \cdot (P_8 + P_{12} + P_{13} + P_{18}) + \\ +3 \cdot (P_{12} + P_{16} + P_{17}) + 4 \cdot P_{19} \tag{11}$$

The average downtime of the first phase, i.e., downtime at customs control:

$$\bar{t}^1_{\mathrm{dwt}} = \frac{1}{\lambda} \cdot (P_1 + P_3 + P_6 + P_0) \tag{12}$$

The average downtime of the second phase, i.e., the downtime during border control, is determined by the formula:

$$\bar{t}^2_{dwt} = \frac{1}{\lambda} \cdot (P_1 + P_2) + \frac{1}{\mu 2} \cdot \begin{pmatrix} P_2 + P_4 + P_7 + P_8 + P_{11} + \\ +P_{12} + P_{13} + P_{19} + P_{16} \end{pmatrix} \tag{13}$$

The average downtime of the third phase, i.e., downtime in other types of state control, is determined by the formula:

$$\bar{t}^3_{dwt} = \frac{1}{\lambda} \cdot (P_0) + \left(\frac{1}{\mu 1} + \frac{1}{\mu 2}\right) \cdot (P_2 + P_4 + P + P_{12} + P_{19}) + \\ + \frac{1}{\mu 3} (P_3 + P_5 + P_9 + P_{19} + P_{17}) \tag{14}$$

Average waiting time for the maintenance of one vehicle:

$$\bar{t}_{\mathrm{wt}} = \frac{1}{\mu 1} \cdot (P_4 + P_{11}) + \frac{1}{\mu} \cdot (P_8 + P_{14}) + \left(\frac{2}{\mu 1} + \frac{1}{\mu 2}\right) \cdot (P_8 + P_{13}) + \\ + \frac{3}{\mu 2} \cdot (P_{13} + P_{17} + P_{18}) + \left(\frac{3}{\mu 1} + \frac{2}{\mu 2}\right) \cdot (P_{12} + P_{16}) + \left(\frac{4}{\mu 1} + \frac{3}{\mu 2}\right) \cdot P_{19} \tag{15}$$

The total time spent by the vehicle in the system:

$$\bar{t}_{\mathrm{sys}} = \bar{t}_{\mathrm{wt}} + \frac{1}{\mu 1} + \frac{1}{\mu 2} + \frac{1}{\mu 3} \tag{16}$$

5. RESULTS OF MODEL IMPLEMENTATION

The proposed model was implemented for a border crossing point between Poland and Ukraine.

The considered checkpoint is classified within the mass service theory as follows:

- nature of receipt of requests – stationary,
- number of requests received at a certain point in time – ordinary,
- connections between requirements – without consequences,
- behavior of requirements – with unlimited waiting,
- method of selecting service requirements – random,

- nature of service requirements – random service time,
- number of service channels – one channel,
- number of service stages – three-phase,
- in terms of the homogeneity of the input stream of vehicles arriving at the border crossing – non-homogeneous,
- open system regarding the limitation of the flow of requirements.

To study the structure of the incoming flow of vehicles at the border crossing between Ukraine and Poland, the primary statistic is a random time interval between two arrivals of vehicles at the checkpoint. The random nature of the receipt leads to the fact that at certain moments a queue is formed at the entrance of the system.

With equal significance, the hypothesis that the continuous random variable is distributed according to the exponential law is verified. The sample size is 500 observations.

The estimate of the parameter of the admissible exponential law is determined:

$$\lambda = \frac{1}{\overline{x_{в}}} \tag{17}$$

$$\lambda = \frac{1}{0{,}52} = 1{,}92 \tag{18}$$

Thus, the differential function of the admissible exponential distribution law is as follows:

$$\mathrm{f(x)} = \lambda \cdot \mathrm{e}^{-\lambda} \tag{19}$$

$$\mathrm{f(x)} = 1{,}92 \cdot \mathrm{e}^{-1{,}92} \tag{20}$$

Empirical and theoretical frequencies were compared using the χ^2 – Pearson test.

Thus, as a result of the processing of statistical data on the intensity of the arrival of vehicles at the border crossing, the parameters of the distribution law of this random variable were obtained:

- mathematical expectation $\mathrm{M(t)} = 0{,}52$ vehicles /hour,
- intensity of the incoming flow of vehicles per hour $\lambda = 1{,}92$ vehicles /hour,
- root-mean-square deviation $\sigma(\mathrm{t}) = 0{,}52$ vehicles /hour,
- coefficient of variation $\nu = \frac{\sigma(\mathrm{t})}{\mathrm{M(t)}} = 1$.

The results of field studies were analyzed, and it was established that the incoming flow of vehicles at the border crossing of Ukraine is distributed according to an exponential law.

In the simulation, the following values of vehicle service intensities at the border crossing were adopted:

- service intensity during customs control $\mu_1 \in [0.1; 0.9]$,
- service intensity during border control $\mu_2 \in [0.1; 0.9]$,
- service intensity during other types of state control $\mu_3 \in [0.1; 0.9]$.

The vehicle capacity of 20 tons is accepted for the consignment. The production capacity of the consignor is 3000 tons/year. The vehicle is loaded at the consignor. The productivity of loading and unloading is 5 tons/ hour.

As the result of model implementation, the technological parameters of the border crossing of Ukraine were determined. With a given incoming flow of vehicles of 1,92 vehicles/hour, the optimal service intensity at the customs point is of 0,255 vehicles/hour, optimal service intensity at the border crossing point is 0,215 vehicles/hour and optimal service intensity when performing other types of control is 0,2 vehicles/hour.

Simulations allowed to obtain the dependence of total costs on certain technological parameters. Examples of dependencies are shown in Figures 1-3.

The obtained dependencies of costs in the entire logistics chain on the intensity of vehicle service during customs control for different values of the intensity of the incoming flow of vehicles at the border crossing are shown in Figure 1. With low values of the intensity of vehicle customs control, the total costs of the entire logistics chain are quite large. This is due to the increase in the length of the queue of vehicles waiting for service. With high values of service intensity, total costs also increase significantly. This is explained by the fact that with an increase in the intensity of service, the costs of maintaining a team of customs officers also increase. Therefore, it is advisable to apply the optimal value of the intensity of vehicle maintenance during customs control.

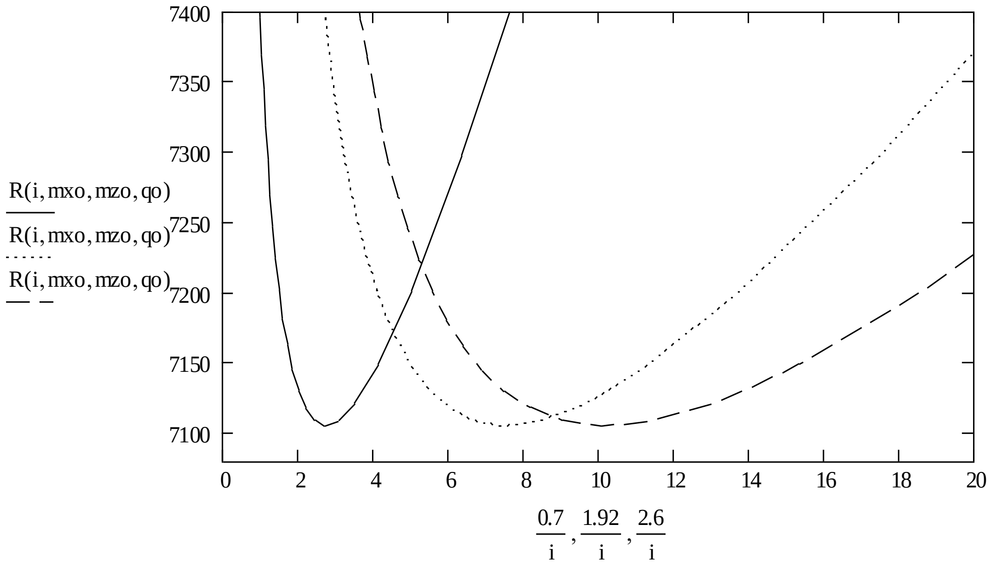

Fig. 1. Dependence of total costs on the ratio of the intensity of the incoming flow to the intensity of servicing vehicles during customs control

The obtained dependencies of total costs on the ratio of the intensity of the incoming flow of vehicles to the intensity of their maintenance during border control are shown in Figure 2. With very small values of the ratio of the intensity of the incoming flow of vehicles to the intensity of servicing vehicles at the customs point, the total costs are very high, and when passing some minimum values, with an increase in this ratio, the costs also increase. Thus, the total costs increase with an increase in the intensity of the incoming flow and decrease with an increase in the intensity of servicing vehicles during border control. At the same time, certain values of the intensity of the incoming flow of vehicles are characterized by certain optimal values of the intensity of their service when passing border control.

The obtained dependencies of total costs on the ratio of the intensity of the incoming flow of vehicles to the intensity of their service when passing other types of control (sanitary, environmental, veterinary, phytosanitary control, control over the export of cultural property from the territory of Ukraine, other state types of control) are shown in Figure 3. Dependencies indicate the presence of optimal values of service intensities when passing other types of control for the corresponding intensities of the incoming flow of vehicles.

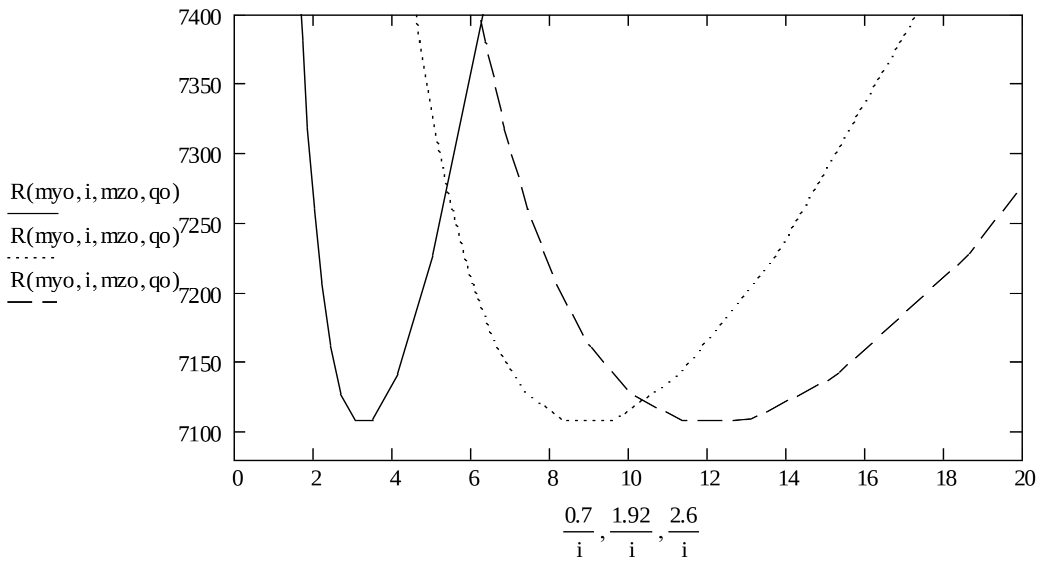

Fig. 2. Dependence of total costs on the ratio of the intensity of the incoming flow to the intensity of vehicle maintenance during border control

The dependence of the absolute throughput on the ratio of the intensity of the incoming flow to the intensity of service at the customs point was obtained (Figure 4). With the increase in the intensity of service at the customs point, the throughput of the checkpoint through the state border increases.

Based on the analysis and evaluation of the simulation results, the following recommendations can be made:

– in order to increase the efficiency of the process of cargo delivery in international traffic, a close relationship between individual links and coordinated actions in the links of the logistics chain are necessary, which will not only reduce costs, but also the waiting time and excessive downtime of vehicles in the nodes,
– at the crossing point across the state border of Ukraine, taking into account the intensity of the incoming flow of vehicles, it is necessary to adjust the intensity of vehicle servicing by the relevant services (customs, border, sanitary, environmental, veterinary, phytosanitary control, control related to the export of cultural property from the territory of Ukraine), which will lead to the minimization of total costs. For this purpose, it is necessary to change the number of personnel in service teams depending on the value of the optimal intensity.

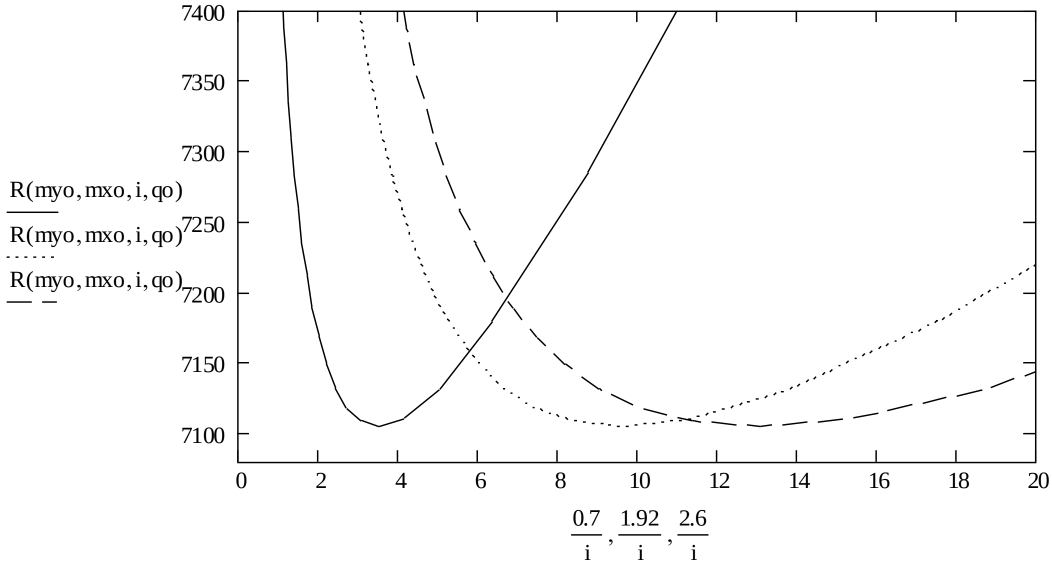

Fig. 3. Dependence of total costs on the ratio of the intensity of the incoming flow to the intensity of service during other types of control (sanitary, environmental, veterinary, phytosanitary control, control related to the export of cultural property from the territory of Ukraine)

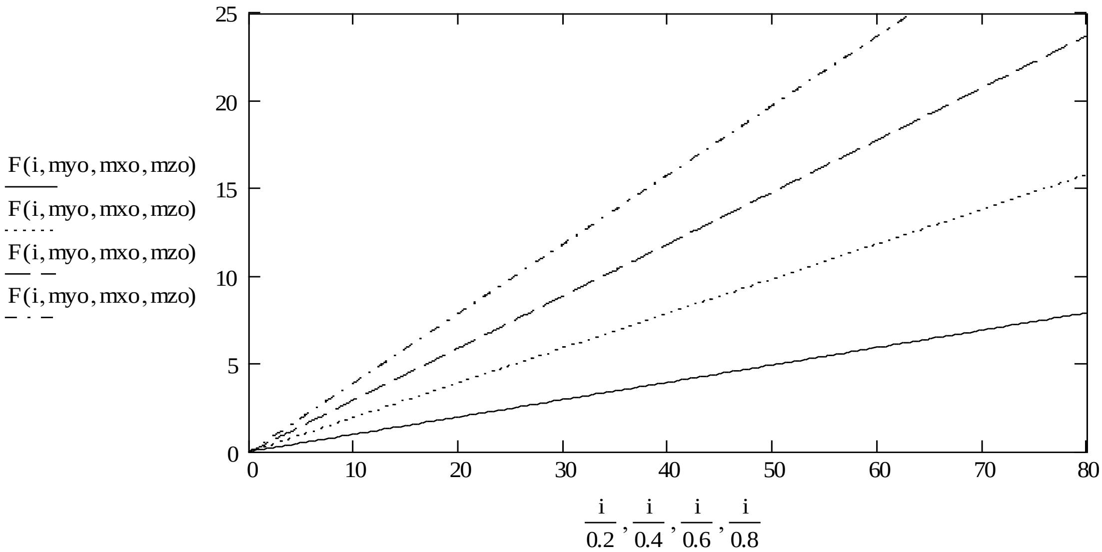

Fig. 4. Dependence of the absolute capacity on the ratio of the intensity of the incoming flow to the intensity of service during customs control

6. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

Based on the analysis of the delivery technology in international traffic and the statistical processing of field research data, a mathematical model was developed, based on a systematic approach and taking into account the costs in the logistics chain of delivery of goods in international traffic.

The scientific interest of the presented model is the optimization of the technological parameters of the goods delivery in international traffic under the conditions of the random nature of the vehicles' arrival at the border crossing, and with the uneven intensity of servicing vehicles by the state administrative services.

The analytical correlation of time spent by vehicles on waiting for servicing and servicing itself at a crossing point is obtained by applying the queuing theory.

As a result of the application of the mathematical model, the handling process at the border crossing can be optimized, which will lead to a reduction of delivery costs in international traffic. The model takes into account the trade-off between the number of border staff and vehicle handling time.

The model was implemented on the example of the border crossing between Poland and Ukraine. The optimal values of the parameters were obtained: intensity of service at the customs checkpoint, intensity of service at the border crossing and intensity of service by other services.

Performed simulations allowed to identify dependencies that enable to assess the nature of changes in costs and technological parameters depending on the intensity of the incoming flow of vehicles and the intensity of vehicles servicing by various administrative services at the border crossing point.

The presented mathematical model of goods supply in international traffic allows optimization of service parameters at the border crossing point, but it can also be used to optimize the functioning of other nodes in the logistic chain of goods supply.

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