Запропоновано модель формування міжнародних логістичних ланцюгів на основі комплексного багатокритеріального аналізу потенційних маршрутів перевезень вантажів та собівартості поставок. Застосування системного підходу при плануванні поставок допомагає забезпечити раціональний розподіл та ефективне обслуговування вантажопотоків за об'єктами транспортно-логістичної мережі.

На першому етапі моделювання проводиться аналіз інформації про об'єкти транспортно-логістичної системи. Визначається область ефективного використання різних видів транспорту та формується множина альтернативних ланцюгів поставок товарів. На основі аналізу впливових факторів визначаються критерії та формуються обмеження задачі за рядом техніко-економічних, логістичних, технологічних, екологічних, тощо, показників. На другому етапі вирішується багатокритеріальне завдання синтезу (проектування) транспортно-логістичної системи поставок.

Розроблено алгоритм для обґрунтування ефективних міжнародних мультимодальних транспортно-технологічних схем доставки вантажів. Запропонований алгоритм містить комплексну оцінку собівартості в залежності від умов поставки за Incoterms та митного режиму. Для обґрунтування маршруту перевезень визначається область ефективних розв'язків для ОПР на основі вирішення задачі векторної оптимізації за декількома критеріями.

Розглянуто формування ефективних схем доставку вантажу з Франції до України за маршрутом з м. О-Моко до складу в м. Дніпрі, «Агро-Союз-Термінал». На основі моделювання за допомогою пакету символьних обчислень в середовищі Maple-7 отриманий повний набор компромісних розв'язків задачі векторної оптимізації за критеріями вартості, часу доставки вантажів та екологічного впливу. Надано комплексну оцінку собівартості поставок вантажів в контейнерах у змішаному сполученні за умов Incoterms EXW, CPT (доставка до Дніпра), FOB та CIF і митного режиму імпорт та імпорт (склад).

Запропонована модель може бути корисною в діяльності транспортних, логістичних, митно-брокерських підприємств при обґрунтуванні альтернативних маршрутів доставки товарів на основі багатокритеріального аналізу інформації

Ключові слова: міжнародні ланцюги поставок, мультимодальні змішані перевезення вантажів, багатокритеріальний аналіз, векторна оптимізація

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DEVELOPMENT OF A MODEL FOR THE INTEGRATED MANAGEMENT OF THE INTERNATIONAL DELIVERY CHAINS FORMATION

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1. Introduction

Ukraine is an important link in the economic cooperation between countries of the European Union and the East as it lies at the intersection of international transportation corridors and has a developed network of highways [1].

Logistics is becoming an important tool for improving the efficiency of the transport system of Ukraine and active integration into the world transportation system. To enhance the integration of Ukraine into the world community, it is necessary to develop a system of container cargo transportation and to implement effective mechanisms for integrated logistics management of container freight flows in the international multi-modal transport-logistics chain [2].

Given the current global trends to increase cargo containerization, it is required that Ukraine should holistically improve the transport and logistics system of multi-modal transportation, improve transport-technological delivery schemes of cargoes in containers when mixed transportation is exploited.

2. Literature review and problem statement

Scientific and technical progress, trends of globalization and regionalization, and increased security requirements make the containerization of cargo transportation the priority factor of the growth of the international trade and improvement of market relations. Competitiveness of container cargo transportations with the use of river transport was analyzed in [3]. The problems of enhancing efficiency and competitiveness of container transportation by rail for the expansion of an existing segment of the transport market are tackled in paper [4]. The issue of formation of the chains of energy timber delivery in central Finland under conditions of the use of container transportation by rail was explored in [5]. However, not enough attention was paid to the issues of organization of effective multimodal container transportation using different modes of transport.

The state of containerization of the international mixed cargo transportation, the level of the Ukrainian container trade and priority directions of containerization development in Ukraine were analyzed in [6]. Effectiveness of organization of the system of security and management of container transportation, an increase in competitiveness of carriers, freight forwarders, logistics and IT-companies depend on comprehensive application of advanced software and hardware tools of control [7]. The problems of micro-logistic planning in ports for efficient management of the flows of empty containers and the cost optimization were discussed in [8]. However, the problems of comprehensive management of formation of the transport and logistic systems of cargo delivery at the macro-level were not sufficiently considered.

Development and active use of modern logistics concepts of multi-modal, inter-modal and combined transport are aimed at enhancement of the overall efficiency of cargo delivery processes, improvement of the package of services, provided in the process of motion from a supplier to a consumer. Comparison of external cost, assessment of economic benefits when using different modes of transport in the multi-modal chain was performed in [9]. The prediction scenarios for participation of the Iranian ports in rendering global container trade and maritime services are analyzed in [10]. Designing the container system of transport networks of internal waterways transportation based on the analysis of ports, service frequency, and the type of vessels was explored in [11]. However, in these models, not enough attention was paid to the issues of determining the spheres of application of various modes of transport in international transportation based of the multicriterial analysis.

In paper [12], it was proposed to model the process of container transportation in the Nord-Pas-de-Calais (France), based on the BPMN approaches to analysis and decision making. The procedure of transformation of the BPMN model into an alternative ACTIF model of the Ministry of transport was proposed.

A comprehensive business process and the model of the multi-modal transport system of container transportation of grain based on the Multi-Agent technology for optimization and management of transport operations were presented in [13].

Optimal management in terms of using various kinds of transport in the container multi-modal system according to the criteria of cost, time and quality of cargo transport was considered based on the method of dynamic programming [14].

A model for solving the problems of a multi-modal transport system of container ships that are associated with demand uncertainty was proposed in [15]. The scientific decision-making tool for operators of multi-modal transport for a simultaneous increase in revenues and meeting the demand of cargo shippers is proposed.

Paper [16] is devoted to modeling of environmental indicators for the multi-modal transportation of three types, such as automobile and marine, railway and marine, river and marine modes of transport. The use of grounded schemes promotes energy efficiency and contributes to obtaining economic benefits.

However, the problem of reasonable selection of multimodal routes of the international delivery of goods, based on the proposed models [12–16], cannot be considered definitively solved. Comprehensive assessment of cost value for international goods shipment was not taken into consideration in the formation of international delivery chains based on multicriterial analysis.

The transport-technological cargo delivery system in containers is a complex system of interacting elements. That is why when choosing the optimum variant of delivery, it is necessary to solve the problem of determining the set of alternatives and to form alternative combinations of different modes of transport for every order [17–19].

In article [17], the schemes were proposed and a criterion of evaluation of alternative variants of transport and goods forwarding servicing of cargo owners at inter-modal goods delivery in containers was formed. Research into modern operation conditions of transport enterprises with the focus on the state of competitive environment, formation of competitive tariffs, which cover the cost of a ship owner and provide a competitive advantage to the carrier, was presented in [18]. The factors that affect implementation of transportation and the criteria, which delivery process participants choose, are taken into consideration in the formation of alternative transport and technological systems of cargo delivery in containers [19]. However, these techniques of forming the schemes of cargo delivery do not resolve the problem of determining an effective set of solutions, based on the methods of vector optimization.

Many applied problems of designing transport systems require optimization by several criteria, which leads to the use of the theory of decision making.

Substantiation of effective organization of various modes of transport in multi-modal container systems by the criteria of time, cost and quality of freight transport, the optimization model, and the algorithm for obtaining optimal combination strategy of transport modes were proposed in [20]. The model of creation of the optimal multi-modal transport network for Randstad district, which, based on multi-purpose optimization, makes it possible to obtain a set of Pareto optimal solutions, was proposed in [21]. Each solution is evaluated for different qualities of promising networks, such as the impact on the environment, accessibility, etc.

Solution of a multicriterial problem of choosing multimodal transportation modes with the use of the BOCR model: B – Benefits, O – Opportunities, C – Cost, R – Risks, based on the method of hierarchy analysis of T. Saaty, is presented in [22].

The multicriterial problem statement and the algorithm for separation of maximum chains by the assigned criterion and evaluation by the others, proposed in [23], were considered on the class of pre-fractal graphs. Multicriterial model of cargo transportation management in the dynamic transport network, taking into consideration the state of routes, the speed, and the weight of a vehicle to minimize the transportation cost was presented in [24]. The comparison of routes by the distance and time criteria, which are considered as competitiveness factors of inter-modal transportation, was performed in [25]. The optimization model that determines the transportation duration, in which the demand throughput in the system is minimized, was proposed in [26].

Paper [27] explored the law of evolution of multi-modal transport systems, taking into consideration the synergetic theory with the use of the model of parameter of the order of multimodal systems for obtaining the order parameter. The equation of co-evolution of the multi-modal transport system taking into consideration interaction and competitive relations between subsystems in order to achieve the optimal system of multimodal transportation was constructed based on the order parameters.

The mathematical model for solving the problem of optimization of multi-modal transportation routes by the criteria of transportation cost, transportation time and transport risks is presented in [28]. The algorithm, which effectively combines the advantages of the algorithms of particle swarm and ant colonies, was proposed. It enables offering an economical and secure plan to those who make transportation decisions.

However, despite many studies on the problem of multicriterial optimization of transport, it is not possible to consider that the development of the problem of ensuring operation coordination of various modes of transport under conditions of interaction of different elements in logistic structures is entirely completed.

At the present stage, extension of understanding the SCM concept as a new ideology of business requires improvement of the processes of integrated delivery management in transport and logistics systems.

The problems of improvement of multi-modal cargo transportations, based on the development and application of logistical strategies are discussed in [29, 30]. However, it is necessary to take into consideration the impact of delivery conditions, based on the Incoterms and the international rules of transportations on delivery cost in order to use these results more effectively.

Methodological approaches to the design of the system of interaction between different modes of transport, based of formation of transport logistical chains in multi-modal transportations, were proposed in [31]. Attention is focused on the mathematical model of formation of the transport logistical chain in direct rail traffic, but no attention was paid to the development and improvement of automobile and water modes of transport and their interactions

Within the logistical system, division of logistics into functional areas implies that these areas are the parts of the unified whole and display the interdependent links of a unified logistic chain. The basic logistic functions such as delivery, warehousing, transportation, sale, information, staff provision, and production and service support are interconnected and mutually subordinated and require comprehensive management [32]. However, methodological approaches to management of the integration of separate functions into a unified system were not presented.

Logistics in the international trading activity has the special feature of operations related to the passage through customs procedures, in drawing up transportation and goods accompanying documents, insurance, etc. Regulation of conditions of goods delivery according to sale and purchase agreements is performed based of the Incoterms and the international transportation rules.

Separate authors explain customs logistics as the applied direction of logistics that connects two interdependent areas – logistics and customs operations. Customs logistics in this case is explained as a separate type of international logistics [33]. This approach does not give grounds for integrated delivery management in transport and logistic systems.

In paper [34], it is proposed to achieve the set goals for management of material flows in international delivery chains due to the comprehensive consideration of the tasks of customs logistics with other spheres of international activity based on logistic approaches. However, no attention was paid to the problem of forming an effective set of delivery routes.

The development of the SCM concept based on improvement of the processes of integrated management of delivery in transport and logistics systems [29–34] contributes to improvement of functioning of logistic systems. However, it is not worth considering that the problem of analysis of modern complex socio-economic systems involving transport process and logistics, which has to be carried out based on an integrated multicriterial analysis, has been completely solved.

The need for development of models based on multicriterial analysis for substantiation of international multimodal transport and technological schemes of cargo delivery is relevant. This is caused by globalization processes taking place in the modern world, and lead to the integration of economies of various countries. The effectiveness of functioning of the international transport and logistic systems requires evaluation by a whole complex of technical and economic, logistic, technological, ecological and others indicators. For a reasonable choice of transportation routes, it is necessary to solve the vector optimization problem by multiple criteria in order to determine the region of effective solutions for a decision maker (DM). It is also important to estimate in integrity the impact of delivery terms according to the Incoterms and the customs regime on delivery cost.

3. The aim and objectives of the study

The aim of this research is to develop a model for formation of the logistic chains of international delivery based on multicriterial analysis of a route and cost of goods delivery in mixed transportation.

To accomplish the aim, the following tasks have been set:

– to form the model for substantiation of effective international multi-modal transport and technological schemes of goods delivery;

– to form a complete set of effective routes of delivery of cargo in containers that get customs clearance with the help of a customs broker enterprise according to the criteria of cost, time, and environmental friendliness;

– to assess the impact of delivery terms of imported goods according to the Incoterms in universal containers and the customs regime on delivery cost.

4. Development of the multicriterial model for formation of logistic chains of international delivery

Management of transport-logistic delivery systems should be considered as a complex problem. At the micro level, it is freight flow management at transformation hubs (enterprises, representing separate elements of the system). At the macro level, the problem should be considered based of the management of delivery chains, taking into consideration that the task is multicriterial.

During substantiation of efficient international multi-modal transport and technological schemes of cargo delivery, the route of mixed transportation should be selected based of vector optimization by several criteria – economic, technical-technological, logistical, environmental, political, etc.

To ensure an effective solution of the problems of comprehensive management of transport-logistic delivery systems, it is advisable to apply the methodology of systemic analysis. Both analysis of individual objects of the system on the micro level, and synthesis during formation of logistic delivery chains at the macro level are required. To assess the delivery effectiveness, it is necessary to conduct a comprehensive analysis of the impact of delivery terms Incoterms and the customs regime on delivery cost.

The model for substantiation of international multi-modal transport and technological schemes of cargo delivery based of the multicriterial analysis is implemented at several stages.

4. 1. Formation of the model based on the analysis of information about objects of transport-logistic system

Stage 1 involves collection and analysis of information about the objects in the transport and logistic system for the development of the mathematical model of multicriterial analysis of alternative chains of goods delivery, determining criteria and stating constraints of the problem.

Step 1. Collection of analytical, statistical and empirical data can be carried out based on different information-analytical sources, including data on the sites of participants in international economic activity, logistic enterprises in the Internet network, as well as through the experiment.

Based on the Google Map resource, possible routes and the length of separate sections were determined [35]. When calculating the cost of certain services, the data of the sites of enterprises TOV "Agro-Soyuz-Terminal" [46], the container terminal of the international trade port "Odessa" [45], the on-line service for sea freight calculation [44], logistic site DELLA [36] were used. On-line services were used for analysis concerning toll road sections [37], ecological zones [38], banning on using cargo vehicles [39] in Europe. Official documents were also used when determining conditions for organization of co-trailer transportations [40], and tariffs for international transportation by rail [41–43].

To determine the region of the effective use of one or another type of transport, it is necessary to identify the factors guiding the carriers. The transportation cost is one of the factors that make it possible to identify the benefits of a particular type of traffic.

Container transportation tariffs, which are established before making a contract, are calculated depending on a cargo type, delivery urgency and many other additional factors.

The components that form the transport cost of a carrier are constantly transformed. Initial cost includes insurance, permission for crossing the border, veterinary, phytoquarantine and ecological control, drawing up TIR carnet, set of CMR invoices, etc. The components of cost include losses through delays at crossing the border, the cost of loading and unloading, travel cost, payment for traveling along the roads of foreign countries. Due to variability of these factors, transportation tariffs also change.

Step 2. Possibility of applying different transport-technological schemes of cargo delivery is considered and a set of alternative goods delivery chains are formed for further analysis.

The process of delivery of goods is affected by a whole range of factors – the total volume of transportation, time, a size of lots, a mode of transport, a kind of the rolling stock, as well as the choice of a delivery route, terms of goods delivery, the application of logistic concepts, etc. Quality functions (criteria) are determined based on the analysis of economic indicators of processes, technological and logistic cost, assessments of the state and dynamic properties of elements of a system, cost of moving and handling freight traffic. The use of the methods of statistical, economic-mathematical, and logistic analysis is effective for evaluation of possible options.

Step 3. Formation of a system of key performance indicators for effective delivery management.

The spheres and tasks of efficient integrated logistic management of delivery are analyzed. Management of flows of foreign economic activity based on the study of the factors of production maintenance, storage, transportation, distribution and use of material resources, information management, and logistics services is considered.

4. 2. Construction of the model based on the synthesis (design) of the transport-logistic system of delivery

At stage 2, a multicriterial task of synthesis (designing) of the transport-logistic system of delivery is solved based on the stated goal and objectives. To implement the model of integrated logistics delivery management, the algorithms that are a basis for formation of a set of efficient solutions for a decision maker (DM), are developed [32, 47 –50].

Step 1. The main goal of logistics is to bring the goods to the final consumer with maximal satisfaction of the needs of the latter. That is why the cost of production is an important indicator in evaluation of effectiveness of application of the Incoterms delivery conditions and the customs regime.

Planning and detailed analysis of the activity of an enterprise makes it possible to select an appropriate customs regime for a particular type of product or raw material. The selection of a customs regime depends on the volume, delivery discipline and cost of goods, weight-dimensional and physical characteristics, etc. The algorithm for selecting the customs regime was proposed in [33]. The improved algorithm uses the Incoterms delivery conditions as an additional criterion for the estimation of the cost value of goods [32].

To solve the problem, the following algorithm is proposed:

– analysis of physical properties of goods;

– analysis of the volume and the plan of goods transportation;

– choice of possible customs regimes. Determining the factors that affect the amount of customs duty and calculation of customs duty for goods;

– choice of possible delivery terms according to the Incoterms. Correction of calculations taking into consideration specific delivery terms;

– calculation of cost of production for all the options. Determining effectiveness of the use of the customs regime and delivery terms;

– comparison of the options.

Step 2. Formation of the model of transport-logistic delivery based on the interpreted multiple structure [47].

1. Formation of the components of the model structure carrier: a set of objects (vehicles, cargoes, warehouses, etc.); cargo handling operations at various stages of transition; algorithms of selection and making decision for proceeding to the next stage.

We present the model of the logistic system of cargo delivery by means of specialized and interpreted multiple structure (1), which is characterized by a hybrid superposition (structure), which includes sets, multi-sets, sorted sets (lists) and non-homogeneous sets (sequences, tuples) [47]:

$$M = (N, \Sigma, \Lambda), \quad (1)$$

where N=GUF is the structure carrier, on the G component of which multiple objects are constructed and F=({, }, [,], (,), <, >, [[,]]) is the alphabet of special symbols; Σ is the signature of relations φ_i=1...4 and operations of superposition Ψ; Λ is the structural axiomatics, which assigns properties, rules of construction of objects, etc.

Component G of the structure carrier (1) will be presented with the sets:

– vehicles (TR), cargo (C), tare (T), suppliers (S), intermediaries (IM), communication routes (roads) (R), customs border check point (CP), consumers (CN), etc., which form a delivery chain at different stages (phases);

– operations of the technological process of cargo handling at each stage $\Omega_I=[\omega_{I,j}]$, $I=I,...,N$; $j=1...j^I$ (N is equal to the number of stages; j^I – to the number of possible technological cycles at stage I);

– algorithms $\Xi_{I,j}$ of decision making as for selection of stage I and correspondent technological cycle j from j^I of possible options.

Algorithms of the decision-making lead to selection of certain elements of the systems and corresponding cycles of technological operations (a set of technological operations in the general case can be empty).

The logistic system G is made up of the set of delivery chains (selectors γ_k), which are formed based on lists γ_{Ijk}= =[[Ω_I, $\Xi_{I,j}$]], I=1...N; j=1...j^I; k=1...s. There selectors form a set from s possible options of delivery and technological cargo handling at each of the stages.

2. Formation of the information model for synthesis of the transport and logistic system includes:

– formation of the management matrix (possible delivery options);

– formation of the information matrix of recourses consumption according to possible options for alternative selection;

– formation of the resources management matrix during designing delivery chains.

Let us consider formation of the information model for synthesis of a logistic system for international cargo delivery with sequential stages I=1...N.

The set of possible technological cycles Ω_I, I=1...N at each stage is made up of lists of operation for each technology of cargo flow handling $[\omega_{I,j,m}]$, I=1...N, j=1...j^I, m=1...$m^{I,j}$. Here, index m determines each of the operations of the cycle of operations j, selected at stage I, and $m^{I,j}$ is equal to the number of operations of selected cycle m.

We form the management matrix for possible options of cargo delivery:

$$\Xi=\left(\theta_{I,j}\right),\quad I=\overline{1,N},\quad j=\overline{1,j^I}.$$

We accept the values of elements $\theta_{I,j}$:

$$\theta_{I,j}=\begin{cases}1, \text{if the technology } j \text{ can be selected in step } I,\\ 0, \text{if the choice of technology } j \text{ in phase } I \text{ is impossible.}\end{cases}$$

We will form the information matrix L, which contains for each of the technological cycles of operations $[\omega_{I,j,m}]$, available for selection at stage I, the cost of implementation $C_{I,j,m}$, time consumption $T_{I,j,m}$ and the characteristic of additional criteria $P_{I,j,m}$:

$$L=\left(\left[w_{I,j,m}\right],C_{I,j,m},T_{I,j,m},P_{I,j,m}\right),$$
$$I=\overline{1,N},\quad j=\overline{1,j^I},\quad m=\overline{1,m^{I,j}}.$$

For each of Q alternative routes (q=1...Q), based on accepted controls ($\theta_{I,j}$) and the information matrix L, we form the resource matrix R for implementation of the options of cargo handling technologies (t=1...T^I), accepted for consideration at each of the stages (I=1...N):

$$R=\left(C_{q,I,t},T_{q,1,t},P_{q,1,t}\right),\ q=\overline{1,Q},\quad I=\overline{1,N},\quad t=\overline{1,T^I}.$$

Step 3. Formation of the multicriterial optimization model based on preliminarily analyzed data.

Analysis of the logistic system of international delivery needs an approach, based on consideration of objects as systems that consist of appropriately structured and functionally organized elements [32]. Representation of systems and separate components using multiple objects was proposed in [47]. In papers [48–50], it was proposed to apply the discrete maximum principle for multistage processes (in the phase method) and vector optimization for formation of efficient transportation and logistic schemes of cargo (goods) delivery.

To select the most effective option, we will form a vector criterion, where delivery time $T(x_1^N)$, delivery cost $C(x_2^N)$, which can be as low as possible, correspond to each from chains γ from Γ. We will represent evaluation of additional factors (environmental, social, military, political, etc.), describing the macrologistic systems, with indicator $P(x_3^N)$, which can be expressed by cost or points according to expert estimates, and will minimize it. We have the vector optimization problem in the form of

$$\begin{pmatrix}x_1^N(\gamma)\\ x_2^N(\gamma)\\ x_3^N(\gamma)\end{pmatrix}\rightarrow \min, \tag{2}$$

where γ belongs to Γ.

Step 4. Solution of the vector optimization problem with the use of discrete maximum principle in the phase method for the problem of integrated management of synthesis of the transport-logistic delivery system.

The specific feature of the problem (2) is the fact that functions of multiple objects serve as indicators. At each stage of advancement of material flows, the composition of multiple objects can change and depends on the selected complex of operations in the process of storage, transportation, customs clearance, etc. A set of technological operations at each stage can depend on the decision that was made at the previous decision step and lead to changes of a delivery chain at subsequent stages, which affects the evaluation of delivery effectiveness in general.

In the topological space with measure $\langle \Gamma,\Re(\Gamma),\mu(\cdot)\rangle$ on $\Re(\Gamma)$, we will introduce function of sets. In the case when these sets contain one point, they represent functions $x_1^N(\gamma)$, $x_2^N(\gamma)$ and $x_3^N(\gamma)$.

The task of vector optimization can be stated as follows. We believe that chain "γ_1" is better than "γ_2" by the indicators, represented by vector criterion (2), by which we imply the Pareto ratio, if

$$\left.\begin{aligned}&x_1(\gamma_1)\le x_1(\gamma_2),\\ &x_2(\gamma_1)\le x_2(\gamma_2),\\ &(x_3(\gamma_1))\le(x_3(\gamma_2)).\end{aligned}\right\} \tag{3}$$

The solution to problem (2) is a set of chains, non-comparable by Pareto, $\Gamma_*\subseteq\Gamma$. Two sets γ_1 and γ_2 from $\Re(\Gamma)$ are non-comparable, if among inequalities (3), there is at least one strict opposite inequality [18].

To ensure optimum management in implementation of the discrete maximum principle in the method of phases, it is necessary to include for consideration at each stage the differential equations, which meet the selectors [48–50]. The transformation equations during cargo transition by phases are represented as follows:

$$x^n = T^n(x^{n-1}, \theta^n), \quad n = \overline{1, N}, \tag{4}$$

where

$$x^n = (x_1^n, \ldots, x_s^n)$$

characterizes the state, and

$$\theta^n = (\theta_1^n, \ldots, \theta_t^n)$$

are the permissible controls at each stage.

The transformation equations for assessment, based on three indicators, have the form of:

$$x_1^n = x_1^{n-1} + t(\omega^n);$$

$$x_2^n = x_2^{n-1} + c(\omega^n);$$

$$x_3^n = x_3^{n-1} + p(\omega^n),$$

where x_1^n is the time to pass the first n phases; x_2^n is the cost of passing the first n phases; x_3^n is the assessment of additional factors (environmental, social, military, political, etc.) during passing first n phases, represented by cost or points by expert estimates; $t(\omega^n)$ is the time of passing the n-th phase; $c(\omega^n)$ is the cost for the n-th phase; $p(\omega^n)$ is the value of indicator for an additional factor in the n-th phase; Ω_n is the list of operations $[\omega_{n,jn}]$ in the n-th phase.

We will accept the following initial values: $x_1^0 = 0$, $x_2^0 = 0$, $x_3^0 = 0$.

The problem of vector optimization is considered

$$\begin{pmatrix} x_1^N \\ x_2^N \\ x_3^N \end{pmatrix} \to \min. \tag{5}$$

Let us introduce the indicator

$$J = \mu_1 x_1^N + \mu_2 x_2^N + \mu_3 x_3^N,$$

where μ_1=1, $\mu_i \geq 0$, i=2...3.

The Hamilton function will be as follows:

$$H^n = z_1^n (x_1^{n-1} + t(\omega^n)) +$$
$$+ z_2^n (x_2^{n-1} + c(\omega^n)) + z_3^n (x_3^{n-1} + p(\omega^n)),$$

where related variables z_1^n, z_2^n and z_3^n are determined from the equations

$$z_1^{n-1} = \frac{\partial H^n}{\partial x_1^{n-1}} = z_1^n; \quad z_2^{n-1} = \frac{\partial H^n}{\partial x_2^{n-1}} = z_2^n; \quad z_3^{n-1} = \frac{\partial H^n}{\partial x_3^{n-1}} = z_3^n$$

with final values

$$z_1^N = \frac{\partial J}{\partial x_1^N} = \mu_1; \quad z_2^N = \frac{\partial J}{\partial x_2^N} = \mu_2; \quad z_3^N = \frac{\partial J}{\partial x_3^N} = \mu_3.$$

Thus, $z_1^N = 1$, $z_2^n = \mu_2$, $z_3^n = \mu_3$, n=1...N.

By sorting out $\mu_i \geq 0$, i=2...3, we obtain the parametric representation of the solution of the vector optimization problem, and besides μ_i, i=2...3, we have the ratio between x_1^n, x_2^n and x_3^n.

Through discreteness of the set of stages of system G, the vector optimization problem (3) has the solution.

5. Formation of effective schemes of cargo delivery from France to Ukraine

5. 1. Selection of alternative routes of goods delivery based on information analysis

Let us consider cargo delivery from France to Ukraine. Transportation of selected development was implemented on the route from Haut-Mauco (France) to the city of Dnipro (Ukraine), "Agro-Soyuz-Terminal". The Internet resource was used to analyze the route [35]. Three routes of cargo delivery from France to Ukraine were accepted for analysis in Fig. 1.

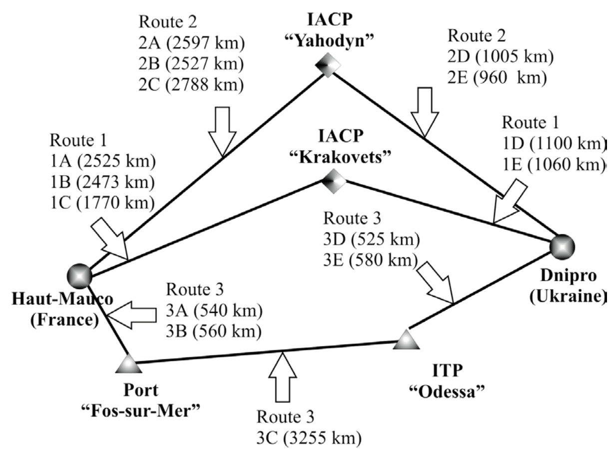

Fig. 1. Schematic representation of cargo delivery routes from France to Ukraine

Route 1 (1A, 1B, 1C) passes through the International automobile checkpoint (IACP) "Krakovets". On this route, we explore three options of delivery to the border. Fast route (1A) of the length of 2525 km implies traveling along toll road sections, the travel time is 22 hours, but we accept 3 days including the rest time of the driver.

Along route (1B) of the length of 2473 km, we avoid toll road sections. Travel time is 26 hours, but we accept 3.5 days taking into consideration the rest time of the driver.

The total distance on route 1C with the use of the mixed option of cargo delivery by road and by rail (container transportation) is 2770 km. We accept delivery time 37 hours since the route does not require taking into consideration time for the driver's rest.

Delivery from IACP "Krakovets" to the city of Dnipro along route 1 includes two possible variants of delivery (1D, 1E in Fig. 1). Fast route (1D) has the length of 1100 km with travel time of over 13 h. A shorter route (1E) has a slower speed due to existence of road sections in the unsatisfactory state. The length of the route is 1060 km, travel time is 15 h.

Route 2 (2A, 2B, 2C) passes through IACP "Yahodyn". On this route, we are considering three options of delivery to the border. The fast route (2A) of the length of 2597 km involves traveling by toll road sections, the travel time is 24.6 h, but we accept 3.3 days including the rest time of the driver.

On route 2B of the length of 2527 km, one travels partially avoiding the toll road sections. Travel time is 27 h, but we accept 3.6 days, taking into consideration the rest time of the driver.

The total distance by the route with the use of the mixed option of cargo delivery by road and by rail (container transportation) (2C) is 2788 km. We accept that delivery time is 39 h since the route does not require consideration of time for a driver's rest.

Delivery from IACP "Yahodyn" to the city of Dnipro along route 2 includes two possible delivery options (2D, 2E in Fig. 1). Route 2D of the length of 1005 km with travel time of 12 hours is longer, but faster. Route 2E is shorter, but the speed on it is lower due to existence of road sections in unsatisfactory state. The length of the route is 960 km, travel time is 13 h.

The third alternative route from the town of Haut-Mauco to the city of Dnipro through the port of Odessa includes two options for a container delivery to the dispatching port "Fos-sur-Mer" (3A, 3B in Fig. 1). The fast route has the length of 540 km with transportation time of 6 h (3A). The long route that bypasses the partially toll road sections has the length of 560 km and duration of 7.30 h (3B).

Delivery from the port of "Fos-sur-Mer" to the port of Odessa (3C) is carried out by sea to a distance of 3,255 km, delivery time is 240 hours (or 10 days).

Two options of the container delivery from the port of Odessa to the warehouse in the city of Dnipro are shown in Fig. 1 (3C, 3D). The long route (3C) of the length of 580 km is faster with travel time of 8 hours. On the short route (3D), due to existence of road sections with unsatisfactory quality of road coverage, the speed is slower, that is why we take 8.2 hours at the length of the route of 525 km.

Analysis of the container transportation tariffs was conducted based on information [36–48], contained at the Internet sites of participants in international economic activity, logistic and other enterprises.

Let us consider the cargo delivery from France to Ukraine by automobile transport. This transportation option makes it possible to perform transportation according to "door-to-door" principle and carry out cargo delivery promptly. Tariffs for freight trucking, unlike other types of transport, are characterized by flexibility and mobility. In addition to the cost, the competitiveness level in the market can have a significant impact on the magnitude of tariff. Transportation cost often takes into consideration the ratio of delivery and demand for transport services [36].

Separate data and calculations in this article are given in national currency of Ukraine, hryvnia (designated as UAH). When we conducted our study (December, 2017), the ratio to currencies of other countries was: UAH 32.96 per one Euro; UAH 27.88 per one US Dollar; UAH 28.17 per one Swiss franc.

The tariff rate for freight transportation in the direction of France – Ukraine, as of December 2017 year, is approximately 38 UAH/km, which is 1.1 EUR/km [36]. Thus, we take into consideration this rate for the analysis of delivery cost.

When calculating the transportation cost, we also include toll road section in Europe. It may be a fare for a road section depending on the covered distance. Special charges, such as the cost of moving through tunnels, bridges, and ferries, can be applied. Or it may be a purchase of "a vignettes", which involves the payment for a specified amount of time (week, month, year) [37]. Traveling by auto thoroughfares of France and Poland is paid. The fare is charged for kilometers actually travelled. Special fee via bridges and tunnels is charged in France and Germany [38].

The passage of the ecological zones of France and Germany and the purchase of an environmental label worth € 15 will be included in the calculations. The penalty for entering an ecological zone without a permit is € 80 [38].

It is known that the passage through European countries (France, Germany, and Poland) for freight transport with permitted maximum weight of more than 7.5 tons is prohibited at weekends from 22:00 on Saturday to 22:00 on Sunday. Similar bans are valid before holidays and on holidays. There are traffic restrictions at night on certain sections of highways, which are marked with signs. There is also prohibition in the summer time – on Saturdays, from July, 1 to September, 31 from 7:00 to 20:00. The prohibition does not apply to combined road-rail transportations from the consignee to the nearest unloading point within a radius of 200 km [39].

Given these limitations, it is advisable to analyze the option of cargo delivery by the combined railway-road mode of transportation (piggy-back transportation) [40]. The advantages of piggy-back transportation are the minimum cargo delivery time, less in comparison with other modes of transport, transportation cost; reduction of negative influence on the environment, safety of goods that are transported, accelerated passage of a train at the border. In some cases, piggy-back transport is an integral part of the route due to the current limitations of the environmental and other nature when it comes to motor transportation. This can be related to axial load limitation, prohibition of movement of heavy trucks on certain days of the week or on specific routes, a poor state of the road surface, the low throughput of the existing roads and others. Calculation for piggy-back transportation was performed according to the international rail freight delivery tariff [41]. Payment for transportation of inter-modal transport units (ITU), except a container or auto vehicles (ATV) in a loaded or an empty condition regardless of an over-dimensionality degree of will be determined by the general tariff rules [41]. The rules apply to the cargo transportation in a car (no less than 10 tons). During cargo transportation in a specialized car, there is a rate per car, which is calculated according to [43]. The rate of the international tariff for transportation of a certain weight category for a specific distance is determined according to [42].

For the option of delivery through IACP "Krakovets", the calculated transportation cost is CHF 2900. For the option of delivery through IACP "Yahodyn", it is CHF 3196. During calculations we take into consideration the additional cost of terminal works like loading-unloading, relocation of a loaded vehicle on a specialized platform of a road-train [42].

We estimate the operations at the checkpoint. On average, the customs inspection time and downtime at checkpoint "Krakowets" is 5 hours, at "Yahodyn", it is 9 hours. If the queue is long, the maximum downtime will be accepted as 1 day. For piggy-back transportation through IACP "Yahodyn", the downtime at a checkpoint is minimal, but we take into consideration the time for operations, connected with a rail width change. For transloading from cars of one rail width to cars of another gauge, for ITO (besides container) and ATV in the loaded state, as well as from/into a car to road transport, a fee in the amount of CHF 95.74 (€ 81.78) is charged [42].

The third alternative option of goods delivery from France to Ukraine is transportation by sea. This is the most economical, but at the same time the longest way of transportation, which makes it possible to transport large amounts of cargo at an affordable price.

Sea freight is calculated based on the use of the Internet resource [44]. Delivery from the port of Fos-sur-Mer to the port of Odessa was accepted as € 316 per 20- feet standard container. The transportation cost will include operations at the port of departure: unloading a container from a motor vehicle and loading it on a ship. The rates of cargo handling operations depend on the maritime line, which brought the cargo, and the terminal, on which the container is handled – the price can fluctuate from € 250 to € 350. Services of a crane at the port are € 170 [44].

At the destination port "Odessa", the cost of unloading and loading of a motor car-container carrier is € 350, or if there is a need to place the goods in a temporary storage warehouse, for example, for 4 days, the fee at the terminal is € 8.22. Additional charge when putting a container from a warehouse on a vehicle is € 39 per 20-foot container [45].

The transportation cost will include payments in a port of destination: ERI – environmental and radiological duty (€ 13), IMP – import duty (€ 20), PAI – additional port charges for imported goods (€ 15), ULI – a ship service fee, charged by a marine agency (€ 20) [44].

For calculations of cargo delivery around Ukraine, we accept approximately 22 UAH/km [36].

At a warehouse, a consigner loads the packed cargo to a universal container and carries out container loading on the platform of a motor vehicle. Let us accept the cost in the warehouse of a consigner with the use of the automated method of loading as 17 Euro/t, with the use of a combined method – 23 Euro/t, for crane services 215 Euro/t.

The unloading cost at the warehouse of a recipient is minimum if a warehouse is in the property. If a warehouse is rented, unloading rates with the combined method, using the palette system are 50 UAH/t. It decreases loading time and cost. But the application is limited by an opportunity to order the production and to use pallets of certain regular sizes. In manual way, we accept the tariff of 60 UAH/t. This method is less demanding, but has a low performance works and certain risks for negligent attitude to the cargo, etc. [46]. For the use of crane, we accept 750 UAH per hour.

5. 2. Analysis of influence of the Incoterms delivery terms and customs regime on delivery effectiveness

Based on the analysis of cargo customs declarations, we will consider the problem of the impact of the customs regime on effectiveness of economic activity implementation on the example of delivery of the product such as quartz sand, fraction 0.1, "SIBELCO" brand, in bags of 25 kg. We accept that delivery is implemented under the following conditions. At buying the wholesale lot of goods, the discount is 25 %. We accept the demand for the product is even, and the term of selling the wholesale batch of product is 3 months.

We will consider the possible options of customs regimes of import and import (warehouse). The calculations will be performed under delivery terms of EXW, SPT (delivery to the city of Dnipro), FOB and CIF.

Under the terms of delivery EXW Haut-Mauco (Yahodyn), a buyer must collect the goods form a seller. In this case, transportation cost increases (delivery from a seller to the border will be accepted as UAH 87,810, the cost of transportation from the border will make up UAH 24,000). Similarly, the delivery under the terms of EXW Haut-Mauco (Krakovets) will also lead to an increase in transportation cost. Under the terms of delivery of CPT (delivery to the city of Dnipro), a buyer does not pay for the delivery, that is, transportation cost is equal to zero. Under the terms of delivery of FOB, a buyer pays for sea freight and the delivery from the port of destination. Under conditions of delivery CIF, a buyer does not pay for sea freight, but only for operations at the port of destination and the delivery to the destination.

We accept the following initial data for calculations. The unit value of product is UAH 244. The magnitude of wholesale lot will be accepted as 5,400 bags of 25 kg. We accept that the customs duty rate is 2 %, the cost of storage in a usual warehouse is 4 UAH/t per day, the weight of the product unit is 25 kg.

At delivery without using a warehouse, purchases are made when necessary. We will accept delivery of six lots every month. In this case, the discount for goods does not apply and delivery cost increases proportionally. Full customs fees are to be paid by each party.

When buying a wholesale lot, the 25 % discount remains, customs fees are paid in full for the entire lot. The product is placed in the warehouse and is used monthly by equal parts. We accept that purchases were made using a credit fund financing at at an annual rate of 24 %.

The most effective scheme of goods import according to the criterion of cost value of goods is determined using the technique with the example, presented in [32].

The calculation results are summarized in Table 1. A comparative chart of cost of goods delivery is shown in Fig. 2.

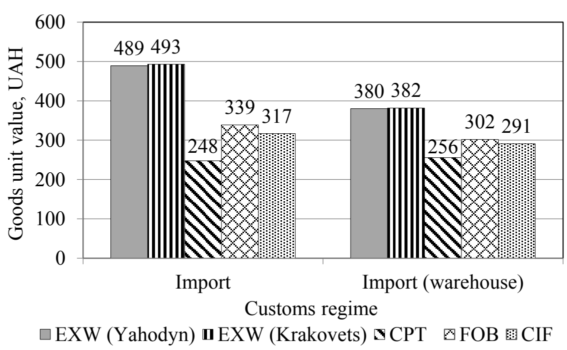

Fig. 2. Comparative chart of goods delivery cost

The data analysis (Table 1) shows that in the "import" mode under delivery terms CPT by road transport, this delivery option is the best compared to others of the studied options by the cost criterion.

Table 1

Results of calculation of cost value of goods delivery, UAH

Customs regime	Indicator						
	Invoice cost of goods	Transportation cost	Total amount of customs fees	The amount paid by an enterprise in first month	Loan cost	Total cost of goods storage	Cost of an item of goods
delivery terms EXW Haut-Mauco (Yagodin)							
Import	1,317,600	1,271,520	51,782	220,075	–	–	489
Import (warehouse)	988,200	529,800	30,360	1,564,560	375,494	128,400	380
delivery terms EXW Haut-Mauco (Krakovets)							
Import	1,317,600	1,292,400	52,200	221,850	–	–	493
Import (warehouse)	988,200	538,500	30,534	1,573,434	377,624	128,400	382
delivery terms CPT							
Import	1,317,600	0	26,352	111,996	–	–	248
Import (warehouse)	988,200	0	19,764	1,024,164	245,799	128,400	256
delivery terms FOB							
Import	1,317,600	475,560	35,863	152,418	–	–	339
Import (warehouse)	988,200	198,150	23,727	1,226,277	294,306	128,400	302
delivery terms CIF							
Import	1,317,600	361,800	33,588	140,925	–	–	317
Import (warehouse)	988,200	150,750	22,779	1,177,929	282,703	128,400	291

5. 3. Determining the region of effective solutions in the formation of delivery chains based on vector optimization

We will consider the problem of vector optimization for the option of the international cargo delivery in a universal container from the town of Haut-Mauco (France) (point A) to the city of Dnipro (Ukraine) (point B). Delivery by road takes place with participation of mediators – IACP Krakovets for Route 1, IACP Yahodyn for Route 2. Delivery by maritime transport involves international ports of Fos-sur-Mer and Odessa for Route 3. We will accept that delivery of a container by road and combined modes of transport (automobile and by railway) from supplier A to consumer B passes five phases (Fig. 3). Phase 1 involves services of a supplier, then delivery by a motor vehicle or container transportation to the border. Phase 3 involves servicing at automobile (railway) checkpoint at the border. Phases 4 and 5 provide delivery by a motor vehicle to the Customs Office of destination and unloading a container from an automotive platform in the warehouse.

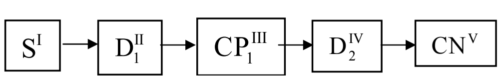

Fig. 3. Scheme of delivery of goods in a container from A to B by automobile and mixed modes of transport: I, II,...,V are the numbers of delivery route stages; S — a supplier; CN — consumer; D_1 — delivery of cargo by automobile transport from the Customs Office in the country of delivery to the border, D_2 — delivery of goods by automobile transport from the border to the Customs Office of destination; CP — international check point at the border

Stages of performance of technological operations are as follows:

$$\Omega_{II}^{S}=\left[\omega_{I,j^{I}}^{S}\right]\rightarrow\Omega_{III}^{D_1}=\left[\omega_{II,j^{II}}^{D_1}\right]\rightarrow\Omega^{CP_1}=\left[\omega_{III,j^{III}}^{CP_1}\right]\rightarrow$$
$$\rightarrow\Omega_{IV}^{D_2}=\left[\omega_{IV,j^{IV}}^{D_2}\right]\rightarrow\Omega_{V}^{CN}=\left[\omega_{V,j^{V}}^{CN}\right].$$

An alternative option involves the delivery of a container by sea from supplier A to consumer B, which passes seven phases (Fig. 4). Servicing of a supplier, delivery by a motor vehicle to the dispatching port and servicing at the dispatching port are the first three phases. Phase 4 is delivery by sea (sea freight). The following three phases include servicing at the port of destination, delivery by a motor vehicle to the Customs Office of destination and unloading a container from an automotive platform into the warehouse.

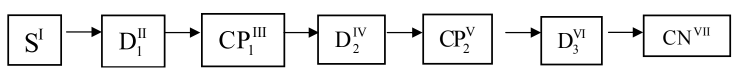

Fig. 4. The scheme of delivery of cargo in a container from A to B by sea freight and by maritime transport I, II,...,VII — the numbers of delivery route stages; S — a supplier; CN — a consumer; D_1 — delivery of cargo by motor transport from the Customs Office in the country of shipment to the port in a country of shipment, D_2 — delivery of goods by sea freight, D_3 — delivery of goods by motor transport from the port of arrival to the Customs Office of destination; CP_1 — servicing at the port of shipment, CP_2 — servicing at the port of destination

Stages of performance of technological operations are as follows:

$$\Omega_{I}^{S}=\left[\omega_{I,j^{I}}^{S}\right]\rightarrow\Omega_{II}^{D_1}=\left[\omega_{II,j^{II}}^{D_1}\right]\rightarrow\Omega_{III}^{CP_1}=$$
$$=\left[\omega_{III,j^{III}}^{CP_1}\right]\rightarrow\Omega_{IV}^{D_2}=\left[\omega_{IV,j^{IV}}^{D_2}\right]\rightarrow$$
$$\rightarrow\Omega_{V}^{CP_2}=\left[\omega_{V,j^{V}}^{CP_2}\right]\rightarrow\Omega_{VI}^{D_3}=\left[\omega_{VI,j^{VI}}^{D_3}\right]\rightarrow\Omega_{VII}^{CN}=\left[\omega_{VII,j^{VII}}^{CN}\right].$$

Thus, cargo delivery by road and by hybrid (container transportation) transportation modes from supplier A to consumer B is performed in the following sequence. A motor vehicle arrives at a warehouse of a provider (P), a cargo is inspected, a container is loaded on the platform and load documents are passed to a cargo carrier. Then transportation to the check point is performed either by Route 1 (D_1) or Route 2 (D_2). Operations at a checkpoint at crossing the border include submission of documents at the customs, customs inspection, customs clearance (CP_1). By the route

(D_3), the cargo is transported by a motor vehicle from the border to the destination Customs Office, where documents are drawn up (CP_2), a container is unloaded from the automotive platform and cargo is placed in the warehouse of a consumer (CN) (Fig. 3).

For alternative Route 3, where delivery is partially carried out by sea, the sequence of operations is as follows. The motor vehicle is sent to a warehouse of a supplier (S), the cargo is inspected. The container is loaded on the platform and load documents are passed to a cargo carrier. Cargo is transported by a motor vehicle to the port of a country of shipment by the route (D_1), a container is loaded aboard a ship, and documents are drawn up (CP_1). Then a cargo is delivered by sea (sea freight) (D_2), it is followed by operations in the port of a destination country, a container is loaded on the automotive platform (CP_2). The cargo is transported from the port of destination to the Customs Office by a motor vehicle (D_3), documents are drawn up at customs office of destination (CP_3), a container is reloaded from the automotive platform and the cargo is placed in a warehouse of a consumer (CN) (Fig. 4).

Preliminary analysis made it possible to state the source data to solve the problem of vector optimization and determine the region of effective solutions for a DM. The number of possible options of technological cycles of operations in each of the five phases for Routes 1 and 2 is determined by the vector

$$J(I)=(2, 3, 2, 2, 3),\ I=1\ldots5,$$

for route 3 – $J(I)=(2, 2, 2, 1, 2, 2, 3)$, $I=1\ldots7$.

Time consumption (days) for implementation of each of the technological cycles is specified in matrix T. Costs (hundreds of €) to perform the relevant operations are specified in matrix C. Estimates of the environmental factors that are expressed with points according to expert estimates are assigned in matrix P. Estimation of the ecological impact on the environment was performed by a degree of harmful emissions of technological operations at each stage by the scale in the range of [0, 1].

For Route 1:

$$C=\begin{pmatrix} 3.5 & 4.5 & 0 \\ 29 & 28 & 32 \\ 0.0001 & 0.0001 & 0 \\ 8 & 7.7 & 0 \\ 0.15 & 0.32 & 0.39 \end{pmatrix};$$

$$T=\begin{pmatrix} 0.125 & 0.16 & 0 \\ 3 & 3.5 & 1.54 \\ 0.2 & 1 & 0 \\ 0.54 & 0.63 & 0 \\ 0.15 & 0.16 & 0.2 \end{pmatrix};$$

$$P=\begin{pmatrix} 0.3 & 0.1 & 0 \\ 5 & 5.5 & 2.5 \\ 0.5 & 1 & 0 \\ 3 & 4 & 0 \\ 0.3 & 0.1 & 0.4 \end{pmatrix}.$$

For Route 2:

$$C=\begin{pmatrix} 3.5 & 4.5 & 0 \\ 30 & 28 & 31 \\ 0.0001 & 0.0001 & 0.8 \\ 7.4 & 7.04 & 0 \\ 0.15 & 0.32 & 0.39 \end{pmatrix};$$

$$T=\begin{pmatrix} 0.125 & 0.16 & 0 \\ 3.3 & 3.7 & 1.62 \\ 0.37 & 1 & 0.125 \\ 0.5 & 0.54 & 0 \\ 0.15 & 0.16 & 0.2 \end{pmatrix};$$

$$P=\begin{pmatrix} 0.3 & 0.1 & 0 \\ 5 & 6 & 2.5 \\ 0.7 & 1 & 0.3 \\ 3 & 3.5 & 0 \\ 0.3 & 0.1 & 0.4 \end{pmatrix}.$$

For Route 3:

$$C=\begin{pmatrix} 3.5 & 4.5 & 0 \\ 6.3 & 6.1 & 0 \\ 4 & 5.2 & 0 \\ 4.16 & 0 & 0 \\ 3.5 & 4.5 & 0 \\ 4.3 & 3.9 & 0 \\ 0.15 & 0.32 & 0.39 \end{pmatrix};$$

$$T=\begin{pmatrix} 0.125 & 0.16 & 0 \\ 0.25 & 0.3 & 0 \\ 0.3 & 0.2 & 0 \\ 10 & 0 & 0 \\ 0.16 & 0.3 & 0 \\ 0.3 & 0.35 & 0 \\ 0.15 & 0.16 & 0.2 \end{pmatrix};$$

$$P=\begin{pmatrix} 0.3 & 0.1 & 0 \\ 0.7 & 1 & 0 \\ 0.6 & 0.5 & 0 \\ 1 & 0 & 0 \\ 0.5 & 0.6 & 0 \\ 1.5 & 2 & 0 \\ 0.3 & 0.1 & 0.4 \end{pmatrix}.$$

The phase method was implemented in the programming environment Maple-7. The obtained selectors γ_k of cargo delivery from A to B, as well as the values of parameters α and μ, the cost of funds for delivery C_k, delivery time T_k and ecological indicator P_k for each of the selectors for Route 1 are shown in Table 2.

Seven selectors of cargo delivery from A to B were obtained. Table 2 shows selectors γ_k, $k=1\ldots7$, representing the sequences of technologies and ways of delivery, selected in each of the phases, as well as cost of delivery C_k, delivery time T_k and ecological estimation P_k for each of the selectors.

The region of effective solutions, obtained in this way, is considered by DM to accept the necessary option. For example, selector γ_1 with the sequence of technological cycles $[\omega_{I,1}]$, $[\omega_{II,2}]$, $[\omega_{III,1}]$, $[\omega_{IV,2}]$, $[\omega_{V,1}]$ and the following values of indicators: C_1=39,35 hundreds of €; T_1=4,61 days; P_1=10,6 points. We have a set of selectors γ_k, k=1...7, which are the solution to the vector optimization problem for Route 1 through IACP "Krakovets".

Results of modeling for Route 2 through IACP "Yahodyn" are given in Table 3. Six selectors γ_k, k=1...6 of cargo delivery from A to B, which form the region of effective solutions, were obtained.

Results of modeling for Route 3 through international ports Fos-sur-Mer and Odessa are shown in table 4. Six selectors γ_k, k=1...6 of cargo delivery from A to B were obtained, which form the region of effective solutions.

Thus, when choosing the option from the region of effective solutions, we see that at savings delivery cost, delivery time simultaneously increases and the impact on ecology of the environment worsens. And vice versa, saving time and decreasing harmful emissions into the atmosphere lead to increased cost of delivery.

Table 2

Options of cargo delivery from supplier A to consumer B through IACP "Krakovets" by Route 1

γ_k	Set of technological operations by phases					α	μ	C_k	T_k	P_k
	I	II	III	IV	V					
γ_1	$[\omega_{I,1}]$	$[\omega_{II,2}]$	$[\omega_{III,1}]$	$[\omega_{IV,2}]$	$[\omega_{V,1}]$	0.01	0.01	39.35	4.61	10.6
γ_2	$[\omega_{I,1}]$	$[\omega_{II,2}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	1.01	0.21	39.65	4.52	9.6
γ_3	$[\omega_{I,1}]$	$[\omega_{II,2}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,2}]$	0.01	0.91	39.82	4.53	9.4
γ_4	$[\omega_{I,1}]$	$[\omega_{II,3}]$	$[\omega_{III,1}]$	$[\omega_{IV,2}]$	$[\omega_{V,1}]$	2.11	0.01	43.35	2.65	7.6
γ_5	$[\omega_{I,1}]$	$[\omega_{II,3}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	3.31	0.01	43.65	2.57	6.6
γ_6	$[\omega_{I,1}]$	$[\omega_{II,3}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,2}]$	0.71	0.91	43.82	2.56	6.4
γ_7	$[\omega_{I,2}]$	$[\omega_{II,3}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,2}]$	0.01	5.01	44.82	2.5	6.2

Table 3

Options of cargo delivery from supplier A to consumer B through IACP "Yahodyn" by Route 2

γ_k	Set of technological operations by phases					α	μ	C_k	T_k	P_k
	I	II	III	IV	V					
γ_1	$[\omega_{I,1}]$	$[\omega_{II,2}]$	$[\omega_{III,1}]$	$[\omega_{IV,2}]$	$[\omega_{V,1}]$	0.01	0.01	38.69	4.885	10.8
γ_2	$[\omega_{I,1}]$	$[\omega_{II,2}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	0.21	0.71	39.05	4.845	10.3
γ_3	$[\omega_{I,1}]$	$[\omega_{II,3}]$	$[\omega_{III,3}]$	$[\omega_{IV,2}]$	$[\omega_{V,1}]$	3.31	0.01	42.49	2.56	6.9
γ_4	$[\omega_{I,1}]$	$[\omega_{II,3}]$	$[\omega_{III,3}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	8.91	0.01	42.85	2.52	6.4
γ_5	$[\omega_{I,1}]$	$[\omega_{II,3}]$	$[\omega_{III,3}]$	$[\omega_{IV,1}]$	$[\omega_{V,2}]$	1.71	1.01	43.02	2.53	6.2
γ_6	$[\omega_{I,2}]$	$[\omega_{II,3}]$	$[\omega_{III,3}]$	$[\omega_{IV,1}]$	$[\omega_{V,2}]$	0.01	5.01	44.02	2.56	6.0

Table 4

Options of cargo delivery from supplier A to consumer B through international ports Fos-sur-Mer and Odessa for Route 3

γ_k	Set of technological operations by phases							α	μ	C_k	T_k	P_k
	I	II	III	IV	V	VI	VII					
γ_1	$[\omega_{I,1}]$	$[\omega_{II,2}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	$[\omega_{VI,2}]$	$[\omega_{VII,1}]$	0.01	0.01	25.31	11.39	5.7
γ_2	$[\omega_{I,1}]$	$[\omega_{II,1}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	$[\omega_{VI,2}]$	$[\omega_{VII,1}]$	4.01	0.01	25.51	11.34	5.4
γ_3	$[\omega_{I,1}]$	$[\omega_{II,1}]$	$[\omega_{III,1}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	$[\omega_{VI,1}]$	$[\omega_{VII,1}]$	7.91	0.01	25.91	11.29	4.9
γ_4	$[\omega_{I,1}]$	$[\omega_{II,1}]$	$[\omega_{III,2}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	$[\omega_{VI,1}]$	$[\omega_{VII,1}]$	12.0	0.01	27.11	11.18	4.8
γ_5	$[\omega_{I,1}]$	$[\omega_{II,1}]$	$[\omega_{III,2}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	$[\omega_{VI,1}]$	$[\omega_{VII,2}]$	11.6	1.41	27.28	11.19	4.6
γ_6	$[\omega_{I,2}]$	$[\omega_{II,1}]$	$[\omega_{III,2}]$	$[\omega_{IV,1}]$	$[\omega_{V,1}]$	$[\omega_{VI,1}]$	$[\omega_{VII,2}]$	5.91	6.11	28.28	11.2	4.4

6. Discussion of results of the application of a model for the substantiation of logistic chains of international delivery

Substantiation of international multi-modal transport and technological schemes of cargo delivery requires development of a comprehensive approach to the analysis of the use of different modes of transport under conditions of effective interaction between the elements in the structure of logistics. Models, based on multicriterial analysis, require development for more accurate representation of the processes of integrated management of delivery in transport and logistics systems.

The approaches to designing logistic chains of international delivery were generalized, developed and found their practical application [32, 47–50]. Multicriterial analysis was used in order to construct an effective route of cargo delivery in containers in mixed traffic. The cost of international delivery was estimated in complex.

The model and multi-step algorithm for substantiation of effective international multi-modal transport and technological schemes of cargo delivery was proposed. The methodological basis is systemic analysis of transportation and logistic systems with their representation in the form of multiple objects [47, 49]. To substantiate the route of cargo transportation, the discrete maximum principle for multistage processes (in the phase method) and vector optimization were applied [48, 50]. The delivery terms by the Incoterms and the customs regime were taken into consideration in determining the delivery cost [32].

An analysis of information about the objects in a transport and logistic system at the first stage of formation of the model helps to formalize a mathematical description of the problem. A system of key performance indicators is formed for effective management of delivery. By analyzing the impact factors, the region of the effective use of the various transport modes is determined, a set of alternative chains of goods delivery is formed, the criteria are determined and restrictions for the problem are stated.

At the second stage, the multicriterial task of synthesis (designing) of the transport-logistic system of delivery is solved based of the stated goal and objectives. The proposed algorithm contains a comprehensive estimation of the cost depending on terms of delivery according to the Incoterms and the customs regime. This task is one of the most important already at the stage of planning of the international economic activity of an enterprise. Thus, the application of the basic conditions of delivery of Incoterms in international transportation makes it possible to avoid disputes between participants of the international goods motion channels and to regulate the process of setting prices for products that are sold.

To substantiate the transportation route, the region of effective solutions according to Pareto for a DM, based on the solution of the problem of vector optimization, is determined. The system of criteria is formed for a specific task by analyzing techno-economic, logistic, technological, ecological, and other indicators.

Application of the methodology of systems analysis in planning delivery offers an opportunity to ensure a rational distribution and efficient servicing of freight traffic for the objects of a transport-logistic network.

The proposed model may be useful in the activity of transport, logistics, customs broker companies in substantiating alternative goods delivery routes based on the multicriterial information analysis.

The analysis of customs clearance of cargoes, made by a customs broker enterprise, was carried out in the study. The paper explores the delivery of cargo from France to Ukraine on the route from the town of Haut-Mauco to the warehouse of “Agro-Soyuz-Terminal” in the city of Dnipro. The use of the data based on cargo customs declarations, available information sources, materials on the Internet sites of the participants in international economic activity, and logistic companies allowed selecting alternative routes for subsequent analysis. Both requirements of the participants for the transportation process, and restrictions that apply in different countries were taken into consideration. Using the model, the region of effective solutions of the vector optimization problem for decision making support on the formation of the international logistics delivery chains by a DM was determined. Modeling was carried out using the package of symbolic computations in the Maple-7 environment and in the Microsoft EXCEL environment.

A full set of compromise solutions to the vector optimization problem for a DM, characterizing cost, delivery time and environmental impact was obtained. These solutions are used to support the process of making a decision about the choice of a transport and technological scheme of transportation on routes that were taken for analysis (Table 2–4).

In the formation of logistic chains of international delivery, the comprehensive analysis of cost was included in multicriterial analysis of alternative routes. The delivery of cargoes in containers in mixed traffic was studied taking into consideration terms of delivery according to the Incoterms and the customs regime. The analysis of options using the customs regimes of import and import (warehouse) under terms of delivery EXW, SPT (delivery to Dnipro), FOB and CIF was carried out.

To improve the proposed model, it is advisable to include the cost value estimation to the multicriterial analysis of transportation and technological schemes and logistic chains of international delivery. To determine the region of effective solutions to the problem of vector optimization with consideration of the impact of delivery terms and the customs regime, the information matrix should include the components of formation of delivery cost.

Subsequent development and improvement of the research are possible in the direction of development of the use of intelligent and information systems and algorithms to solve problems of multicriterial analysis of transportation and logistic systems.

7. Conclusions

1. The model and a multi-step algorithm were proposed for the substantiation of effective international multi-modal transport and technological schemes of cargo delivery.

At the first stage of the formation of the model, information about the objects in the transport and logistic system is analyzed. The region of effective use of various transport modes is determined, and a set of alternative chains of goods delivery is formed. Based on the analysis of the impact factors, the criteria are determined and restrictions of the problem are formed. This helps to formalize a mathematical description of the vector optimization problem for several technical, economic, logistic, technological, environmental, and other indicators.

At the second stage, the multicriterial problem of synthesis (designing) of the transport-logistic system of delivery is solved. The proposed algorithm contains a comprehensive assessment of the cost depending on delivery terms according to the Incoterms and the customs regime. To substantiate the transportation route, the region of effective solutions for a DM, based on the solution to the vector optimization problem by several criteria is determined.

The model, proposed in the paper, makes it possible to perform a multicriterial evaluation in formation of international logistics chains, taking into consideration the potential routes of transportation and cost of delivery.

2. Based on the analysis of the delivery of cargoes that are customs cleared by a custom-brokerage enterprise, an example of formation of effective schemes of cargo delivery from France to Ukraine along the route from Haut-Mauco to the warehouse "Agro-Soyuz-Terminal" in Dnipro was studied.

The region of efficient solutions to the vector optimization problem for support of making decisions on the formation of the international logistic delivery chains by a DM was determined by modeling using the package of symbolic computations in the Maple-7 environment. A full set of compromise solutions to the vector optimization problem by the criteria of cost, delivery time and environmental impact on the environment was obtained.

3. A comprehensive analysis was performed of the cost of cargo delivery in containers using mixed transportation under conditions of the EXW, SPT Incoterms (delivery to Dnipro), FOB and CIF, and the customs regime of import and import (warehouse).

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