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МОДЕЛЮВАННЯ ЗАДАЧ ТРАНСПОРТУ ТА ЕКОНОМІКИ

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INTERNATIONAL LOGISTICS SYSTEMS DESIGN AND EFFECTIVENESS EVALUATION

Purpose. In the paper the question of the development of a methodological approach to the determination of logistics systems' performance and grounding of the most effective goods' delivery schemes, based on the theory of functions and sets of multiple objects, vector optimization approaches and discrete maximum principle for multi-stage processes (phase method) is considered. **Methodology.** To achieve the goals of the research, the model of logistic system is represented by the multiple object, it is defined by the structure and content. The object is represented by hybrid superposition, composed of sets, multi-sets, ordered sets (lists) and inhomogeneous sets (sequences, corteges), which at each stage of cargo delivery present sets of technological operations of their processing, choices and decisions algorithms. Multiple structure of objects is constructive three, consisting of the carrier, signatures and axiomatic. To determine the effective scheme of delivery, discrete maximum principle using vector optimization criterion is applied. **Findings.** In this article logistics system of delivery is presented in the form of a multi-stage (phase) of the process. Each stage reviews a plurality of discrete activities sets, which includes the possible technology cycles of operations in goods handling. At each stage of a multi-phase delivery process from the supplier to the consumer, these sets are different. A model example solving the problem of vector optimization options for delivery of goods by the road in the international logistics system for the five-step process is considered. Optimization is performed on the basis of three indicators. **Originality.** In this paper, the choice of the most effective way of delivery goods is produced using the theory of functions and sets of multiple objects, using the discrete maximum principle for multi-stage processes, based on the vector optimization criterion. At each of its stages are formed a plurality of valid solutions as discrete sets of technological cargo handling operations cycles. **Practical value.** The proposed approach to the modeling of logistic delivery goods systems on the basis of the theory of functions and sets of multiple objects, vector optimization approaches and discrete maximum principle for multi-stage processes (phase method) makes it possible to assess the efficiency of delivery in logistic system's modeling. The choice of the most effective delivery option, based on vector optimization criterion becomes more possible.

Keywords: efficiency of logistics systems; discrete maximum principle; multiple objects; vector optimization; efficiency of delivery

Introduction

The current stage of logistics development is characterized by the appearance of fundamental changes in the organization and management of market processes in the global economy [7]. There is an opportunity to monitor all phases of the product moving through modern communication technologies. There is an actively developing field which provides services in the field of logistics. Conceptual provisions of logistics, its integration role become recognized of the majority of logistic processes participants. It takes holistic set of conductive-material subjects.

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The process of globalization is one of the major trends in the development of macrologistical systems in the world today and is manifested in the interdependence and interpenetration of national economies [8]. The development of macro logistics is under influence of the regional economy characteristics. Regionalization is manifested at the level of individual countries as well as international scope. Formation of numerous integration ties between the regions of the country, as well as with foreign countries necessitates logistics management of interregional numerous material, attendant financial and information flows.

The diversity and complexity of the processes were shown in the modelling of foreign economic activity macrologistical system [10]. Meeting the challenges in macrologistical system is done by simulation of a set of tasks that are qualitatively and quantitatively characterize each of the stages – providing material resources; production, storage, transportation, distribution of material resources, information management; flow control at border crossings and logistics services; targeted use of material resources. In a globalized world economic processes appeared the necessity to include into the model tasks of customs logistics and consideration in conjunction with other areas of international activities.

Logistics system can be considered, dividing it into three levels [4]. The first, spatial one is manifested through connection between the elements of the system and goods flow and belong to the task of logistical chain localization, places to demand creation, communication networks between these units. The second, organizational level covers methods of organization and supply chain management for the purpose of mutual coordination functions of the individual elements of the logistics system in the scope of the operational, financial and marketing management functions. The third, information level, is defined as the flow of funds and information. At each level, there are streams, as well as the relationships between the elements of the corresponding structures. These tightly interconnected elements together form a single conglomerate, which reflects the multidimensional nature of the logistics system. This equally applies to the macro and micro logistics.

Among the fundamental principles of logistics stand out the principle of logistics system total costs optimization, which include operational logistics costs (costs of transportation, warehousing, materials handling, etc.), Transaction and other administrative costs [6].

Goals of macrologistical systems creating significantly differ from the objectives and criteria of micrologistical systems synthesis. In most cases, the criterion of minimum total logistics costs was used in the synthesis of macrologistical systems. However, the most common criteria for the formation of macrologistical systems are determined by environmental, social, military, political, and other objectives [9].

Successful supply chain management requires cross-functional integration of key business processes within the firm and across the network of firms that comprise the supply chain. It is focused on the management of key relationships and the improvements in performance that can be achieved [14].

The contribution of research [13] lies in the development of a new decision support approach that is flexible and applicable to logistics service providers, in selecting multimodal transportation route under the multi-criteria in term of cost, time, risk and importantly the environmental impact.

Tasks associated with the movement of material flow in logistics can be considered as a multistage (phase) process. However, they belong to different functional areas and require a comprehensive review on the basis of many criteria for rational and (or) optimal use of resources throughout the logistics system. Thus, the task of analyzing the international logistics system can be formulated as a problem of vector optimization [3].

Purpose

We represent the logistic system of cargo delivery in the form of several successive stages (phases). At each stage, we consider the multiplicity of discrete activities sets, which includes possible technological cycle of operations in cargo handling. At each stage of multi-phase delivery process from the supplier to the consumer, these sets are different and form a multiplicity of sets (lists) technological operations $W = [W_I, W_{II}, ..., W_N]$, available to the alternative or joint selection at each stage. Each stage comprises a set of technological operations $\mathrm{W}_I = \{[\omega_{j(I)}^{k(j)}]\}$, $I = \overline{\mathrm{I}, N}$, where: N – the number of phases, which are determined by the index I. Index $j(I)$ indicates possible sets of ac-

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tions on stage I. Each of the operations of the selected process cycle is indicated by the index $k(j)$. Process operations are subject to selection, based on algorithms $\Xi_i = \{\theta_i\}, i = \overline{1, N}$ for each of the stages I. Logistics system Γ consists of many supply chains, which are formed based on lists $\gamma_{Ijk} = [[W_I, \Xi_1], [W_{II}, \Xi_2], ..., [W_N, \Xi_N]]$ and are options of cargo delivery.

The theoretical approach to the definition of logistics systems performance – based on theory of functions set and multiple objects, vector optimization approaches and application of the discrete maximum principle for the processes that contain series of successive phases, proposed in [11].

To determine the most effective option, we formulate a vector criterion, where each of the chains γ from Γ corresponds the time of delivery T (x_1^N), delivery expenses C (x_2^N), which should be as small as possible. Assessment of additional factors (environmental, social, military, political, etc.) that characterize macrologistical system, we present by indicator P (x_3^N), which can be expressed in costs or points according to expert estimates and minimize it. We write a criterion as:

$$\begin{pmatrix} x_1^N(\gamma) \\ x_2^N(\gamma) \\ x_3^N(\gamma) \end{pmatrix} \to \min \qquad (1)$$

where $\gamma \in \Gamma$.

Methodology

Considered indicators are functions of multiple objects [1, 2, 12, 15, 16]. At each stage of material flows, promotion of multiple objects composition may vary, depending on selected set of operations in the process of storage, transportation, customs clearance, and others. A set of technological operations at each step may depend on the adopted at the previous step solutions and lead to changes in logistics circuit at later stage, which affects the assessment of overall delivery efficiency.

We introduce a topological space $\langle \Gamma, \Re(\Gamma), \mu(\cdot) \rangle$. We introduce the function $\Re(\Gamma)$ on the sets. In the case where these sets contain the one point, they will be $x_1^N(\gamma), x_2^N(\gamma)$ and $x_3^N(\gamma)$.

Mathematically the variation of process steps in the formation of the supply chain at each stage of the movement, expressed by the operation of symmetric difference of two sets, which includes «needle variation» by McShane [15]. Then, to determine the optimal value of the logistic system, considered the task of function set optimization [3].

For the introduced topological space with measure we use the derivative of the function sets as:

$$\left.\frac{dF(A)}{d\mu}\right|_{\{B_n\}\to B\neq} = \frac{F(A\Delta B) - F(A)}{\mu(A\Delta B) - \mu(A)}$$

Vector optimization problems can be formulated in such way. We consider that the chain is «γ_1 better than γ_2» on the indicators, presented by the vector criterion (1), which refers to the ratio of Pareto if

$$\left.\begin{matrix} T(\gamma_1) \le T(\gamma_2) \\ B(\gamma_1) \le B(\gamma_2) \\ P(\gamma_1) \le P(\gamma_2) \end{matrix}\right\} \qquad (2)$$

Solution of the problem (1) is a set of incomparable by Pareto chains $\Gamma_* \subseteq \Gamma$.

Two sets γ_1 and $\gamma_2 \in \Re(\Omega_{ЛС})$ are incomparable, if among the inequalities (2) there is at least one strict reverse inequality.

According to (1) determine the rule of selection (criterion) of «best» sets. This is known as the Pareto ratio [3].

Due to the discreteness of the multiple stages Γ, the task of vector optimization (1) has a solution.

During the formation of the supply chain, the following variation of the set may be possible:

1) variations at certain stages in the sets of technological operations. The purpose of such modifications is to enhance the system's efficiency or to optimize technological cycle. Such changes do not affect the effectiveness of the following steps in the selected supply chain of goods and cargo.

2) variations, which occur in decision making on specific stage, which affect all the subsequent steps and should be considered for evaluating the effectiveness for each of the subsequent stages, as well as the whole chain in general. An example of such a variation is, for example, the choice of

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transportation mode for delivery or logistical intermediary etc.

Formation of the supply chain is shown in fig. 1, where a comparison of each $W \in \Omega$ of W_{nj} set is a multi-valued mapping. It is firstly shown the formation of all the system's elements based on decision-making Ξ_i (design): selection of the cargo type for transportation, packaging, choice of route, customers, suppliers and intermediaries, the definition of the border crossing checkpoints between states etc. Next shown phases (process steps) W_I which passes the cargo, moving from the supplier to the consumer, displaying cycles of technological operations at each stage, elected on the basis of decision-making Ξ_I.

Circles highlight selected in accordance to the algorithm Ξ_i elements of multi-stage freight (goods) delivery system without additional technological operations selection. Squares outline elements of the system, the selection of which by the algorithm Ξ_i entails the relevant manufacturing operations execution on selected objects, shown as the lists $W_I = \{[\omega_{j(I)}^{k(j)}]\}$, $I = \overline{I, N}$.

Fig. 1 line γ_1, which connects the objects shows one embodiment of the formation of the supply chain in the logistics system Γ in a result of decision-making Ξ_i'. Possible variations in the performance of a specific set of technological cycle indicated by the line γ_1'. Line γ_2 shows another embodiment of delivery chain which is formed as a result of decision Ξ_i''.

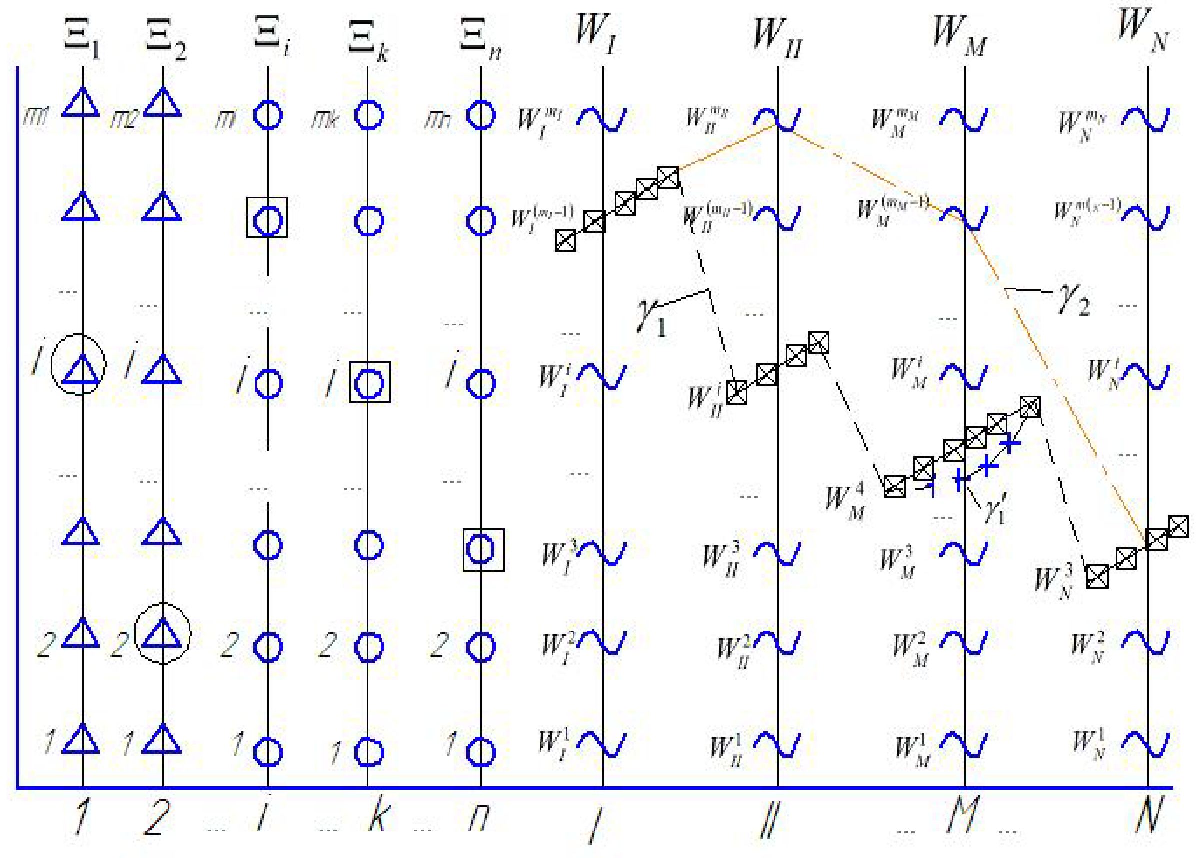

Fig. 1. Geometric representation of a multivalued mapping

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Transformation equation for loads delivery in phases [5]

$$x^n = T^n(x^{n-1}, \theta^n), \quad n = \overline{1, N} \tag{3}$$

where $x^n = (x_1^n, \dots, x_s^n)$ characterizes the state at each stage, and $\theta^n = (\theta_1^n, \dots, \theta_t^n)$ – admissible controls.

Acceptable controls

$$\theta^n \in \Xi, \; n = \overline{1, N} \tag{4}$$

The initial state $x^0 = x^t$.

It is necessary to find θ^n, $n = \overline{1, N}$ which satisfy (4) to

$$J = \Phi(\mathrm{x}^{\mathrm{N}}) \to \max \tag{5}$$

We introduce the Hamiltonian function

$$H^n = \sum_{i=1}^{s} z_i^n T_i^n(x^{n-1}, \theta^n), n = \overline{1, N} \tag{6}$$

and conjugated system

$$z_i^{n-1} = \frac{\partial H^n}{\partial x_i^{n-1}}, \; i = \overline{1, s}; n = \overline{1, N} \tag{7}$$

with the boundary conditions

$$z_i^N = \frac{\partial \Phi(\mathrm{x}^{\mathrm{N}})}{\partial x_i^N}, \; i = \overline{1, s} \tag{8}$$

Possible variation of the Hamiltonian function

$$\delta H(\bar{\theta}) = \sum_{i=1}^{t} \frac{\partial H(\bar{\theta})}{\partial \theta_i} \delta\theta_i \tag{10}$$

where $\bar{\theta}$ and $\bar{\theta} + \delta\theta$ belongs to the domain of admissible controls.

Terms of optimal control and application of the maximum principle for discrete processes are described in [5] and given in [11].

Let the delivery of cargo from point A to point B occurs in N phases. Accept that a multistep process is simple, consists of stages with one input and the output.

Justification of the generalized maximum principle for the case where at each stage of cargo movement $I = \overline{I, N}$ formed its own range of feasible solutions W_I, shown in [11]. The evaluation was conducted based on three indicators.

Transformation equations have the form

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

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

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

where x_1^n – the time for completion of the first phase; x_2^n – the cost of the passage of the first phase; x_3^n – assessment of additional factors (ecological, social, military, political, etc.) during the passage of the first n phases, presented by costs or points according to experts; $t(\omega^n)$ – passage of n-th phase, if the event ω^n is accepted; $c(\omega^n)$ – cost of funds for the n-th phase if the event ω^n is accepted; $p(\omega^n)$ – values for an additional factor in n-th phase, if the event ω^n is accepted; W^n – set of activities in n-th phase.

The initial values $x_1^0 = x_2^0 = x_3^0 = 0$.

The problem of vector optimization

$$\begin{pmatrix} x_1^N \\ x_2^N \\ x_3^N \end{pmatrix} \to \min. \tag{11}$$

We introduce a measure

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

where $\mu_1 = 1$, $\mu_i \geq 0, i = \overline{2, 3}$.

The Hamiltonian function is follow

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

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

$$z_1^{n-1} = \frac{\partial H^n}{\partial x_1^{n-1}} = z_1^n;$$

$$z_2^{n-1} = \frac{\partial H^n}{\partial x_2^{n-1}} = z_2^n;$$

$$z_3^{n-1} = \frac{\partial H^n}{\partial x_3^{n-1}} = z_3^n.$$

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With final values

$$z_1^N = \frac{\partial J}{\partial x_1^N} = \mu_1 ;$$

$$z_2^N = \frac{\partial J}{\partial x_2^N} = \mu_2 ;$$

$$z_3^N = \frac{\partial J}{\partial x_3^N} = \mu_3 .$$

In this way,

$$z_1^n = 1,\ z_2^n = \mu_2,\ z_3^n = \mu_3, n = \overline{1, N} .$$

The Hamiltonian in this case takes the form

$$H^n = x_1^{n-1} + \mu_2\, x_2^{n-1} + \mu_3\, x_3^{n-1} + (t(\omega_i^n) +$$

$$+\mu_2\, c(\omega_i^n) + \mu_3\, p(\omega_i^n)) .$$

minimal value at decisions which are taken, defined as follows

$$t(\overline{\omega}_i^n) + \mu_2\, c(\overline{\omega}_i^n) + \mu_3\, p(\overline{\omega}_i^n) =$$

$$= \min_{\omega_i^n \in W^n} (t(\omega_i^n) + \mu_2\, c(\omega_i^n) + \mu_3\, p(\omega_i^n)) .$$

Thus, brute $\mu_i \geq 0, i = \overline{2, 3}$, we obtain a parametric representation of the vector optimization problem solution, and excluding $\mu_i, i = \overline{2, 3}$, we get the relationship between x_1^n, x_2^n and x_3^n.

Findings

Consider the example of a model for solving the task of vector optimization for case of international container shipping by truck from the supplier A to the consumer B with one conciliator – international automobile checkpoint (IAC) at the border. Accept that the delivery of the goods is carried out in five phases: service provider; delivery to the border by a car; service at border crossings; delivery to the consumer and the consumer service.

We assume that the number of technological cycles of operations in each phase determined by the vector $M = \begin{pmatrix} 3 & 2 & 5 & 1 & 4 \end{pmatrix}$. Amount of time (quantity of days) for performing each of the technological cycles given in the matrix T. Expenses (thous. $) to perform the corresponding operations are given in the matrix C. The matrix P shows expenses (thous. $) To ensure environmental safety of transport:

$$C := \begin{bmatrix} 1 & 3 & 5 & 0 & 0 \\ 4 & 7 & 0 & 0 & 0 \\ 6 & 8 & 10 & 20 & 50 \\ 17 & 0 & 0 & 0 & 0 \\ 2 & 5 & 9 & 15 & 0 \end{bmatrix}$$

$$T := \begin{bmatrix} 10 & 6 & 5 & 0 & 0 \\ 4 & 2 & 0 & 0 & 0 \\ 6 & 5 & 4 & 3 & 2.5 \\ 1.7 & 0 & 0 & 0 & 0 \\ 3 & 2.5 & 2.1 & 1.5 & 0 \end{bmatrix}$$

$$P := \begin{bmatrix} 11 & 7 & 5 & 0 & 0 \\ 5 & 3 & 0 & 0 & 0 \\ 6 & 5 & 4 & 3 & 2.5 \\ 2.7 & 0 & 0 & 0 & 0 \\ 4 & 3.5 & 2.1 & 1.5 & 0 \end{bmatrix}$$

Realization of the phase method is implemented in Maple-7 environment. Calculations were carried out by changing parameters μ_2, μ_3 from 0 to 10 in increments of 0.01. Thus were obtained nine different selectors γ_i of cargo delivery from A to B.

Table 1 shows the selectors $\gamma_i, i = \overline{1, 9}$ that represents the sequence of selected in each of the phases technologies, as well as the costs for shipping C_i, delivery time T_i and environmental costs P_i for each of selectors.

Two of the resulting solutions of vector optimization task shown in fig. 2 (*a, b, c*), 2 (*d, e, f*). On the axes of graphs displayed parameters (run-time of operations, the expenses and environmental costs) for the selectors to ensure the fulfilment of the vector criterion (11). Axis identifiers correspond to the serial number of the selector given in the table 1. Selectors, beginning from the vertical axis directed upwards, are taken in that order (clockwise) that with increasing delivery costs parameters characterizing the time of delivery and the costs of environmental safety, reduces.

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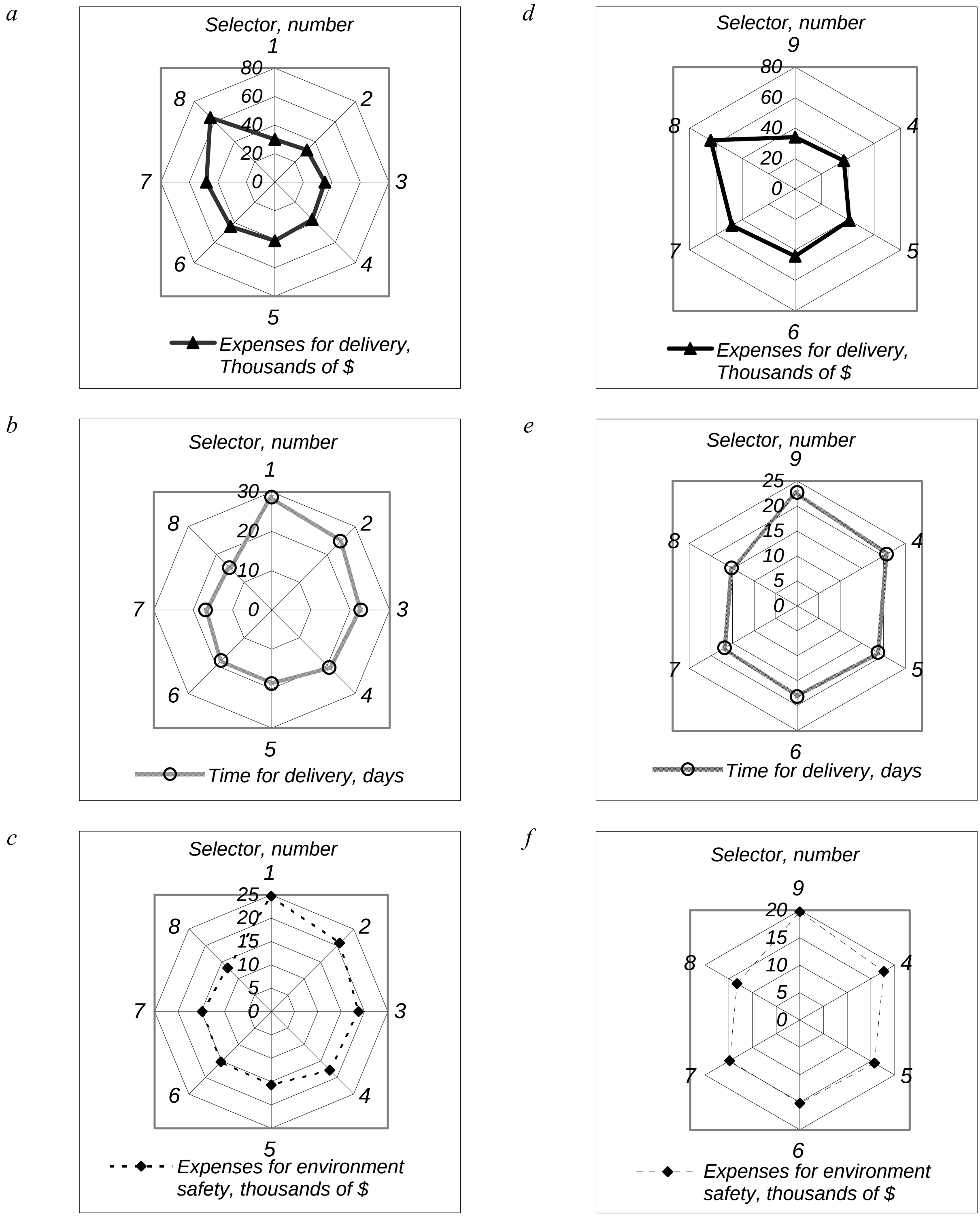

Fig. 2. Solutions to the vector optimization problem: axis identifiers «1» … «9»
indicate the number of selector from tab. 1.

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Table 1

Options for delivery from the supplier A to the consumer B

Selector	The set of technological operations in phases					Expenses for delivery C_i, Thousands of \$	Time for delivery T_i, days	Expenses for environment safety P_i, thousands of \$
	I	II	III	IV	V			
γ_1	$W_{I,1}$	$W_{II,1}$	$W_{III,1}$	$W_{IV,1}$	$W_{V,1}$	30	24,7	28,7
γ_2	$W_{I,2}$	$W_{II,1}$	$W_{III,1}$	$W_{IV,1}$	$W_{V,1}$	32	20,7	24,7
γ_3	$W_{I,2}$	$W_{II,2}$	$W_{III,1}$	$W_{IV,1}$	$W_{V,1}$	35	18,7	22,7
γ_4	$W_{I,2}$	$W_{II,2}$	$W_{III,1}$	$W_{IV,1}$	$W_{V,1}$	37	17,7	20,7
γ_5	$W_{I,3}$	$W_{II,2}$	$W_{III,3}$	$W_{IV,1}$	$W_{V,1}$	41	15,7	18,7
γ_6	$W_{I,3}$	$W_{II,2}$	$W_{III,3}$	$W_{IV,1}$	$W_{V,2}$	44	15,2	18,2
γ_7	$W_{I,3}$	$W_{II,2}$	$W_{III,3}$	$W_{IV,1}$	$W_{V,3}$	48	14,8	16,8
γ_8	$W_{I,3}$	$W_{II,2}$	$W_{III,4}$	$W_{IV,1}$	$W_{V,4}$	64	13,2	15,2
γ_9	$W_{I,3}$	$W_{II,1}$	$W_{III,1}$	$W_{IV,1}$	$W_{V,1}$	32	20,7	24,7

The effective solutions area, obtained thus way, considered by the decision maker (DM), to take the necessary option. For example, the axis of the identifier «1» in fig. 2 (*a, b, c*) corresponds to the selector γ_1 with sequence of technological cycles $W_{I,1}$, $W_{II,1}$, $W_{III,1}$, $W_{IV,1}$, $W_{V,1}$ and the following values of parameters: C_i = 30 thousand. \$; T_i = 24.7 days; P_i = 28.7 thousands. \$. The axes with identifier «2» – selector γ_2. Thus, we have a sequence of selectors γ_1, γ_2, γ_3, γ_4, γ_5, γ_6, γ_7, γ_8, which represent the solution of vector optimization. On separate diagrams represented each of the three indicators: for the first option – in fig. 2 *(a, b, c*) and to the second – in fig. 2 (*d, e, f*).

Originality and practical value

In this paper the choice of the most effective way of delivery goods produced using the theory of functions and sets of multiple objects, using the discrete maximum principle for multi-stage processes, based on the vector optimization criterion. At each of its stages are formed a plurality of valid solutions as discrete sets of technological cargo handling operations cycles.

The proposed approach to the modeling of logistic delivery goods systems on the basis of the theory of functions and sets of multiple objects, vector optimization approaches and discrete maximum principle for multi-stage processes (phase method) makes it possible to assess the efficiency of delivery in logistic system's modeling and choose the most effective delivery option, based on vector optimization criterion.

Conclusions

The paper shows the application of the discrete maximum principle for evaluating the effectiveness of the goods delivery in logistical system of delivery modelling in the form of a multi-stage (phase) process, where at each stage of cargo movement $I = \overline{I, N}$, formed its own range of feasible solutions W_I, representing a plurality of discrete sets of activities, which includes possible technological cycle of operations in cargo handling.

The logistic system model presented as multiple object that contains a set of technological operations of cargo handling, as well as the algorithms of choice and decision-making at every stage.

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To select the most efficient delivery options, formulated vector criterion which based on three indicators as well as considered model example of vector optimization task solving.

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ПРОЕКТУВАННЯ ТА ОЦІНКА ЕФЕКТИВНОСТІ МІЖНАРОДНИХ ЛОГІСТИЧНИХ СИСТЕМ

Мета. В роботі розглянуто питання формування методологічного підходу до визначення показників ефективності логістичних систем та обґрунтування найбільш ефективних схем доставки вантажів (товарів) на основі теорії функцій множин і множинних об'єктів, підходів векторної оптимізації й дискретного принципу максимуму для багатоетапних процесів (у методі фаз). **Методика.** Для досягнення цілей дослідження модель логістичної системи представлена множинним об'єктом, який визначається структурою й змістом. Об’єкт також представляється гібридною суперпозицією, складеною із множин, мультимножин, упорядкованих множин (списків) та неоднорідних множин (послідовностей, кортежів), які представляють на кожному з етапів доставки вантажів набори технологічних операцій їх обробки, алгоритми вибору й прийняття рішень. Множинна структура об'єктів представляється конструктивною трійкою, що складається з носія, сиг-

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натури й аксіоматики. Для визначення ефективної схеми доставки вантажів застосований дискретний принцип максимуму з використанням векторного критерію оптимізації. **Результати.** У статті логістична система доставки вантажів представлена у вигляді багатоетапного (фазового) процесу. На кожному етапі розглядається множина дискретних наборів заходів, що включає можливі технологічні цикли операцій при обробці вантажу. На кожному з етапів багатофазного процесу доставки вантажу від постачальника до споживача ці множини різні. Розглянуто модельний приклад рішення задачі векторної оптимізації для варіанта доставки вантажу автомобільним транспортом у міжнародній логістичній системі для п’ятиетапного процесу. Оптимізація здійснюється на основі трьох показників. **Наукова новизна.** У даній роботі вибір найбільш ефективного варіанта доставки вантажів здійснюється з використанням теорії функцій множин та множинних об'єктів, із застосуванням дискретного принципу максимуму для багатоетапних процесів на основі векторного критерію оптимізації. На кожному з етапів відбувається формування своєї множини можливих рішень у вигляді дискретних наборів заходів технологічних циклів операцій по обробці вантажу. **Практична значимість.** Запропонований підхід до моделювання логістичних систем доставки вантажів на основі теорії функцій множин та множинних об'єктів, підходів векторної оптимізації й дискретного принципу максимуму для багатоетапних процесів (у методі фаз) дає можливість оцінювати ефективність доставки вантажів при моделюванні логістичної системи. Можливим також стає вибір найбільш ефективного варіанту доставки на основі векторного критерію оптимізації.

Ключові слова: ефективність логістичних систем; дискретний принцип максимуму; множинні об'єкти; векторна оптимізація; ефективність доставки вантажів

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ПРОЕКТИРОВАНИЕ И ОЦЕНКА ЭФФЕКТИВНОСТИ МЕЖДУНАРОДНЫХ ЛОГИСТИЧЕСКИХ СИСТЕМ

Цель. В работе рассмотрен вопрос формирования методологического подхода к определению показателей эффективности логистических систем и обоснованию наиболее эффективных схем доставки грузов (товаров) на основе теории функций множеств и множественных объектов, подходов векторной оптимизации и дискретного принципа максимума для многоэтапных процессов (в методе фаз). **Методика.** Для достижения целей исследования модель логистической системы представлена множественным объектом, который определяется структурой и содержанием. Объект также представляется гибридной суперпозицией, составленной из множеств, мультимножеств, упорядоченных множеств (списков) и неоднородных множеств (последовательностей, кортежей), которые представляют на каждом из этапов доставки грузов наборы технологических операций их обработки, алгоритмы выбора и принятия решений. Множественная структура объектов представляется конструктивной тройкой, состоящей из носителя, сигнатуры и аксиоматики. Для определения эффективной схемы доставки грузов применен дискретный принцип максимума с использованием векторного критерия оптимизации. **Результаты.** В статье логистическая система доставки грузов представлена в виде многоэтапного (фазового) процесса. На каждом этапе рассматривается множество дискретных наборов мероприятий, которое включает возможные технологические циклы операций при обработке груза. На каждом из этапов многофазного процесса доставки груза от поставщика к потребителю эти множества разные. Рассмотрен модельный пример решения задачи векторной оптимизации для варианта доставки груза автомобильным транспортом в международной логистической системе для пятиэтапного процесса. Оптимизация осуществляется на основе трех показателей. **Научная новизна.** В настоящей работе выбор наиболее эффективного варианта доставки грузов производится с использованием теории функций множеств и множественных объектов, с применением дискретного принципа максимума для многоэтапных процессов на основе векторного критерия оптимизации. На каждом из этапов происходит формирование своего множества допустимых решений в виде дискретных наборов мероприятий технологических циклов операций по обработке груза. **Практическая значимость.** Предложенный подход к моделированию логистических систем доставки грузов на основе теории функций множеств и множественных объектов, подходов векторной оптимизации и дискретного принципа максимума для многоэтапных процессов (в методе фаз) дает возможность оценивать

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эффективность доставки грузов при моделировании логистической системы. Возможным также становится выбор наиболее эффективного варианта доставки на основе векторного критерия оптимизации.

Ключевые слова: эффективность логистических систем; дискретный принцип максимума; множественные объекты; векторная оптимизация; эффективность доставки грузов

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