Methods of evaluation of efficiency of logistic operations

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Abstract

In accordance with the strategic course chosen by Ukraine in the Armed Forces of Ukraine, the transformation of the management system based on the principles of joint leadership of the defense forces must be completed. The main purpose of the transformation is to ensure the maximum efficiency of the use of heterogeneous forces and means of the Armed Forces of Ukraine in the interests of the tasks. One of the components of the transformation is the transition to a logistics system. The introduction of logistical approaches to the management of material resources aims to provide in the shortest possible time with minimal costs and losses of military formations (units) with material means.

Therefore, the paper proposes a method for evaluating the effectiveness of logistics operations. The initial data are determined in the method at the first stage.

At the second stage, the hierarchy of the logistics system with the subsystems of management bodies, warehouses with material resources, restoration of weapons and military equipment, provision of the material means, transportation, etc. is presented. However, on the example of the subsystem of material support, priority technical means have been identified that will be used to perform logistics operations using the method of analysis of hierarchies.

At the third stage, applying the method of the maximum element, rationally distributed forces and means of logistics for the timely provision of military formations with material means.

At the fourth stage, to avoid threats that arise on the routes of technical means, taking into account the terrain, road conditions, etc. using the method of dynamic programming determined the rational route of maneuvering technical means during the task.

At the fifth stage, using the method of a progressive standard, a comparative analysis and evaluation of technical means involved in the implementation of logistics operations.

Key words: restoration, provision, weapons and military equipment, material means, material flows, optimization, rational distribution, technical means, logistics operations.

Introduction

The readiness of military formations (units) to load troops for combat missions is largely fulfilled by the quality of the functioning logistics systems (The main provisions, 2016). Indeed, untimely restoration of damaged samples of weapons and military equipment, untimely provision of material means leads to untimely performance of the assigned task and in some cases in general to disruptions in the task due to the lack of working samples of weapons and military equipment, material means for their repair, material means for the life of military formations (units), etc.

Therefore, in the paper (Dachkovskyi, V., 2020) a set of principles for building a system for the restoration of weapons and military equipment, which takes into account not only many elements of the system of restoration of damaged samples of weapons and military equipment, but also many elements to provide repair and restoration units with the necessary material means.

In the paper (Dachkovskyi V., Yaroshenko O., 2020) some elements of the restoration system

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of damaged samples of weapons and military equipment are considered, where a methodical approach is suggested to definition the structure of repair and restoration bodies, which will perform the task of restoring damaged samples of weapons and military equipment. Such elements of the recovery system as reliability, the number of recovered samples of weapons and military equipment according to the nomenclature at each level of the hierarchy is considered in the paper (Dachkovskyi V., Kotsiuruba V., 2020), and the efficiency of the system of recovery of weapons and military equipment by the magnitude of the probability of performing a set of works performed for a given time is considered in the paper (Dachkovskyi V., Strelbitskyi M., 2020). In the paper (Dachkovskyi V., Ways of determining, 2020) approaches to assessing the quality of repair of damaged samples of weapons and military equipment are proposed.

Accordingly, for the timely provision of military formations (units) of the material means in the paper (Dachkovskyi, V. O., 2020) a material flows optimization method is proposed. However, to assess the quality of the functioning of the material means supply system in accordance with the proposed method in the paper (Dachkovskyi, V. O., 2020) there is a need to develop a methodology that will allow to assess the effectiveness of logistics operations, namely, to determine the technical means that will be used to perform tasks and their rational distribution by tasks, the choice of rational routes of transportation of the material means, etc.

Material and methods

A number of works, both by domestic and foreign scientists, have been devoted to the study of the provision and recovery of weapons and military equipment in the performance of their assigned tasks, in particular the paper (Ivanova, M. I., 2015) is devoted to the study of the main conceptual approaches to the definition of "logistics" and the clarification of this concept taking into account the characteristics of the object of management, and in the publication (Stupnytsky O. I., 2014) the features of formations of logistics crisis situation in the context of military-political conflict and forms of its interaction with military logistics are analyzed. In the literature sources (Seagull, I.P., 2017) the essence of marketing management of activity of the enterprise as scientific category of marketing activities was analyzed and it was proposed to systematize the work on consumer development, and in the paper (Tyurina, N. M., 2011) the integration of marketing and logistics concepts of management was analyzed. As a result, it is proposed to increase competitiveness by implementing the concept of marketing and logistics management. Some aspects of this issue are outlined in the paper (Tarasenko, A., 2013), which is devoted to the analysis of the interpretation of the conceptual and categorical apparatus on the essence and content of logistics of the security and defense sector of Ukraine, and the paper (Yelagin, Yu. V., Hoop G. V., 2014) is devoted to research of directions of development of transport logistics, the main types of transport logistics and its main functions are highlighted. The treatment of this problem is also reflected in the publication (Alkema V. G., 2007) which is devoted to assessing the effectiveness of the warehouse. A brief overview of sources on the efficiency of warehousing logistics is given, and in the paper (Kunitskaya, O. M. Mandro, L. A., 2012) the main issues facing organizations regarding warehousing are considered, namely the issues of design and organization, improvement of the technological process of warehousing. In the literature sources (Vnukova, N. M. Kolodizeva, S. O.; Dovzhenko, O. O. Mel'nychuk, O. S., 2011) the theoretical aspects of banking logistics are considered and the modern directions of introduction and realization of logistic approaches in practice of management of the enterprises are analyzed. In the paper (Velichko, O. P.) features of logistics management through subject-object relations and communication of the main types of logistics are considered, and in the paper (Melnikova K. V., 2017) the principles on which the system of logistic service of consumers is based are analyzed and the sequence of actions concerning formation of system of logistic service is defined. In the paper (Savich O. P., 2016) the model of movement of cars from manufacturers to the final consumer is offered, and in the paper (Volinchuk Yu. V. Kudelya I. O., 2013) features of logistic management of supply process are considered. The difference between the concepts of "procurement logistics" and "supply logistics" was analyzed the main stages of logistics management of the supply process are identified. In the paper (Solodka, O. V.) the theoretical content and meaning of logistics, the essence of competitiveness and the main tasks that logistics perform to ensure competitiveness have been revealed. Consideration of the directions of logistics support of innovative processes and the essence of the DFL concept is devoted to the work (Humenna O. V., 2015), and in the paper (Komarnytsky, I. M. Pytulyak, N. S., 2008) the analysis of processes of formation of warehouse logistics is carried out and proposed criteria for the division of warehouses into groups on the basis of which the structuring of warehouses by groups and types. In the paper (Parikh, P. J. Zhang, X. Sainathuni, B., 2010) the model for integration of the warehousing solutions with stocks and transportation for the minimization of the distribution cost is proposed.

In the paper (Fahimnia, B. Luong, L. Marian, R., 2008) a comprehensive analysis of the model of products distribution and a description of its main characteristics are proposed. Mixed supply network is proposed on the basis of production and transportation (distribution) plans, and in the paper (Heilala J., Vatanen S., Tonteri H.) an integrated modeling tool is suggested to help to maximize the effectiveness of the production and to balance the environmental restrictions that exist at the systems design stage. The work (Law A.M., McComas M.G., 2000) is devoted to the optimization of the production process, and the paper (Hajnal E., Kollar G., 2005) The work is devoted to modeling on software. This software provides the ability to simulate warehousing operations and allows you to test different scenarios. The paper discusses what the technological approach in logistics means, why we should optimize the warehouse network, how to measure changes during modeling and what result can be achieved. The paper (Daofang C., Jinfeng Z., Danping L., 2015) is devoted to minimizing operating costs when designing a logistics chain by setting a target function. Since logistics chains are built depending on demand, the concept of "service radius" is proposed in the work, which means the time of transportation between logistics nodes for their service. The research in the work (Mukhamedjanova K. A., 2020) is devoted to the analysis of the theoretical foundations of supply chain management. Three main stages of development of logistics deliveries were considered, three main stages of development of logistics supplies were considered namely the formulation of the concept and coordination of actions, integration of key functions, focusing on the needs of end users and other types of competition in logistics chains. The work (Sam Sekhar M, Venkata Chalapathi, 2019) is devoted to the study of the value of the supply chain, namely the procedure for registration of incoming goods. To minimize the total costs, the issue of the type of packaging and containers for each nomenclature of the material means is considered. In the work (Jabir Arif, Khaoula Azzouz, Youssef Mouzouna, 2020) the strengths of logistics services with the use of identification are analyzed. A new approach to integrating the identifier into the logistics outsourcing process using telemetry of transport messages is proposed, which will allow to receive data about events in real time. In the work (Saleh Alyahya, Ashit Kumar Dutta, 2020) technologies of identification of material means which give the chance to facilitate and automate work on information management by means of radio waves and problems which arise at the same time are investigated. To collect information and process it, a method of optimizing identification technology using fuzzy logic is proposed, which allows to obtain incomplete data and get better results.

Therefore, the purpose of the article is to develop a methodology for evaluating the implementation of logistics operations, which on the basis of initial data would provide the opportunity to determine the necessary technical means to perform appropriate logistics operations, rationally distribute them, determine a rational route and conduct a comparative evaluation of relevant technical means.

Results and discussion

The structure of the methodology, which would provide an opportunity to assess the effectiveness of logistics operations to provide military formations (units) of material means in accordance with the proposed method (Dachkovskyi, V. O., 2020) will be considered in five stages:

I stage – definition of initial data;

II stage – assessment of priorities for the use of technical means of logistics to provide military formations (units) material means;

III stage – rational distribution of resources to provide material means;

IV stage – choice of rational routes of movement, maneuver of technical means for transportation of material means;

V stage – comparative analysis of technical means used to perform logistics operations.

Since the first stage of the method is considered in detail in works, we turn to the next stage.

At the second stage, for effective management of material flows circulating in the general logistics system, an appropriate system should be created, which includes a subsystem of management bodies, a subsystem of warehouses with material means, a subsystem of weapons and military equipment restoration, a subsystem of material means, transport subsystem, etc. (Havryliuk, I., Matsko, O., Dachkovskyi V., 2019). Since the logistics system is a complex system and includes various subsystems in which perform specific tasks, then to simplify the assessment of priorities for the use of technical means, consider the example of the subsystem of material means.

According to the work (The main provisions, 2016) for effective performance of tasks by military formations (units) the logistics system must timely supply the following nomenclatures of material means:

automotive equipment (AQ) and automotive property (AP);

armored equipment and technology (AET), armored property (AP);

missile and artillery armament and missile and technical property;

engineering weapons machines, and engineering property, etc.;

other types of material mean in accordance with the classes of supply.

The process of providing military formations (units) with appropriate material means can be represented as a hierarchy fig. 1.

It is possible to draw a conclusion about the advantage of some technical means over others that affect the implementation of logistics operations based on the comparison of certain indicators: location of the warehouse, economic costs, production capacity, operational, management automation. Accordingly, for each indicator we allocate its components, namely:

location of the warehouse: 1 – delivery time of material means, 2 – distance from the warehouse to the military formations (units), 3 – possibility of roads for technical means, 4 – security of the warehouse;

economic cost: 5 – cost of technical means, 6 – maintenance costs of technical means, 7 – the cost of transportation of material means, 8 – the cost of repairing of the technical means.

production capacity: 9 – time of loading (unloading) of material means on technical means, 10 – maintenance time of one technical means, 11 – warehouse turnover, 12 – the number of completed tasks.

exploitative: 13 – maintainability of technical means, 14 – security of technical means, 15 – increased permeability of technical means, 16 – load capacity of technical means;

management automation: 17 – processing of data on accounting of material means in the warehouse, 18 – data processing to determine the location of material means during their transportation, 19 – processing of data on the need to replenish material means to the warehouse from higher-level warehouses, 20 – processing of data on the purchase of material means which are not enough.

The choice of technical means for transportation of material means will be carried out in accordance with certain requirements in the works (Dachkovskyi, V., 2019; Dachkovskyi, V., 2020), that is, the option A_1 technical equipment with increased level of protection against means of defeat, payloads of up to 5 tonnes, increased level of off-road passability, with a possibility of self-loading etc., the option A_2 technical equipment protected against means of defeat, with a load capacity of up to 10 tonnes, with increased off-road capability, self-loading etc., the option A_3 technical means are unprotected from means of defeat, with a carrying capacity of more than 10 tonnes, etc.

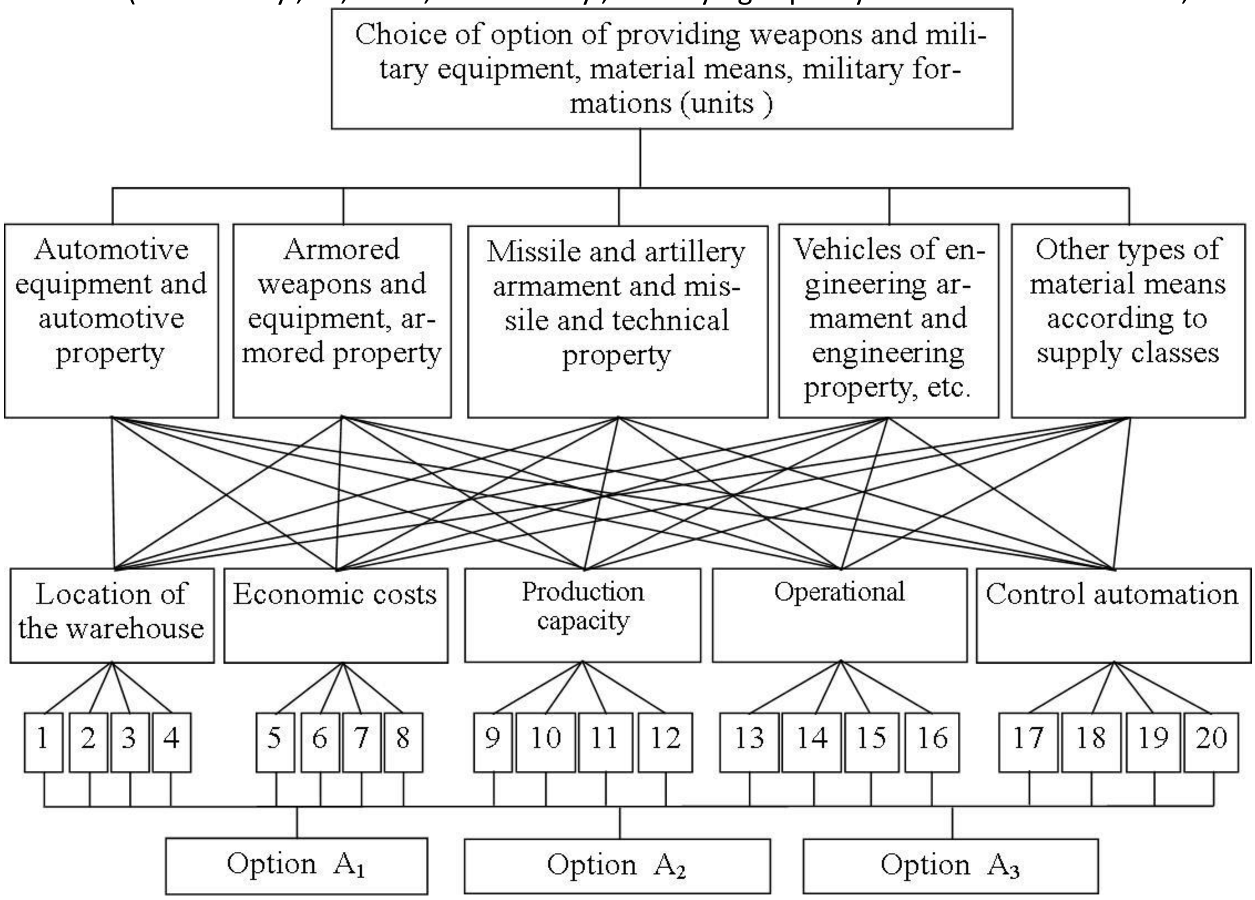

Fig. 1 Hierarchical representation of the problem of choosing technical means and methods of transporting of material means

The positive factors of all options for the use of technical means to perform logistics operations, which are considered, are:

pre-positioned determination of the presence of material means in the relevant warehouses;

determination of the optimum route of transportation of material means;

reduction of time for transportation of material means;

reduction of loading time (unloading) of material means;

reduction of transportation costs of material means.

A qualitative analysis of technical means that operate at different levels of the hierarchy shows that they are characterised by a significant number of unequal, interrelated subjective and objective factors. This does not allow only by logical analysis to immediately select the technical means that would be acceptable on all grounds with a certain degree of compromise. Therefore, to solve the problem of setting priorities for technical means A_1, A_2, A_3, which will be used to carry out logistics operations, it is proposed to use a hierarchy analysis method.

As shown in fig. 1 hierarchy is built from the top through intermediate levels to the bottom level, which is usually a list of alternatives. In our case, such a structure of the figure of the problem is called the dominant hierarchy (Kotsyuruba V.I., Matsko O.Y., Chernykh I.V.).

The experts made a pairwise comparison (Kotsyuruba V.I., Matsko O.Y., Chernykh I.V.; Lubintsova, V. S.; Gurch L.M.): how much more desirable it is to use a particular technical means to meet each component of the fourth level of the hierarchy. In our case, we get twenty expert opinion matrices of dimension 3 × 3, as there are twenty constituent indicators at level 4 and three technical means options, which are compared for each of the components. The matrix of pairwise comparisons is square, its general form for the *l*-th characteristic is given in (Litvak B.G.).

The matrix has the property of inverse symmetry, that is $a_{jil} = 1/a_{ijl}$, where the indices i and j refer to row and column, respectively. In this case $i,j = \overline{1,n}$ (n – is the number of alternatives – options for technical means). For the example under consideration, $i,j = 1,2,3$.

The matrix cells, which are located on its diagonal, are equal to one $a_{11l} = a_{22l} = \ldots = a_{ijl}(i = j) = \ldots = a_{nnl} = 1$. The matrix cells are filled by experts as follows. If the element A_1 dominates the element A_2, then the cell that belongs to a row A_1 and a column A_2, filled with a number a_{12l}, and the cell that corresponds to the row A_2 and the column A_1, is filled with an inverse number, that is $a_{21l} = 1/a_{12l}$. If the element A_1 and A_2 are the same, then one is placed on these two cells. The number of expert judgments in the matrix of pairwise comparisons is determined by the formula

$$C = \frac{n(n-1)}{2} \quad (1)$$

A scale of relative importance has been proposed for experts to make pairwise comparisons in the works (Kotsyuruba V.I., Matsko O.Y., Chernykh I.V.; Litvak B.G.; Attetkov A., Galkin S., Zarubin V., Asanov M. O.).

When involving a group of R experts for the evaluation of options for the use of technical means, the numerical value of the judgment is defined as the geometric mean of individual expert judgments:

$$a_{ij1} = \sqrt[R]{\prod_k a_{ij1k}}, \ k = \overline{1,R}, \quad (2)$$

where a_{ijlk}– judgment of the k-th expert.

The appointment of experts is carried out in accordance with their competence on the use of technical means for logistic operations, level of position, work experience.

From the group of matrices of paired comparisons, a set of local priorities is formed, which express the relative influence of the set of elements on the level element adjoins to the top. To do this, the eigenvectors are calculated for each l–th, $l = \overline{1,L}$ (L – the number of matrices of the fifth level of the hierarchy) matrices of pairwise comparisons and the result are normalized.

The definition of local priorities is carried out in the following sequence:

for each row l–th of the matrix is determined by the geometric mean of the formula

$$b_{il} = \sqrt[n]{\prod_j a_{ijl}}, j = \overline{1,n}, i = \overline{1,n}; \quad (3)$$

rationing of geometric averages is carried out (the estimation of a vector of priorities is received)

$$X_{il} = \frac{b_{ij}}{\sum_i B_{ij}}, \ i = \overline{1,n}; \ l = \overline{1,L}, \sum_i X_{ij} = 1. \quad (4)$$

Coherence of local priorities (matrix of pairwise comparisons) is characterized by the coherence index (Kotsyuruba V.I., Matsko O.Y., Chernykh I.V.; Zhukovin V. E.).

It is defined as follows (Zhukovin V. E.):

the sum of judgments (elements) of each column of a matrix of pair comparisons is defined

$$r_{jl} = \sum_i a_{ijl}, \ j = \overline{1,n}, \ i = \overline{1,n}; \quad (5)$$

the value is calculated $\lambda_{max\,l}$, for this, the sum of the first column is multiplied by the value of the first component of the normalized priority vector, the sum of the second column is multiplied by the value of the second component and so on

$$\lambda_{max\,l} = r_{1l}X_{1l} + r_{2l}X_{2l} + \ldots + r_{jl}X_{jl} + \ldots + r_{nl}X_{nl}; \tag{6}$$

Then, the consistency index is calculated (*CI*)

$$CI_l = \frac{\lambda_{max\,l} - n}{n-1}, n\rangle 1, \tag{7}$$

thus, for an inversely symmetric matrix always $\lambda_{max\,l} \geq n$.

In the paper [44] the average consistencies for random matrices of different order are given.

Random consistency is obtained by random selection of quantitative judgments according to the scale and the formation of an inversely symmetric matrix.

The consistency ratio (CR) is defined by dividing the *CI* by a number that corresponds to the random consistency of the matrix of the same order. The value of the CR should be no more than 10% (Litvak B.G.). In some cases, the CR may be close to 20%. When the CR exceeds these limits, it is necessary to investigate the correctness of the problem and check the judgments of experts.

According to the hierarchical figure of the problem of choice of technical means by experts at the fourth level twenty matrices of pair comparisons are formed. These matrices contain estimates or judgments of experts on the relative importance of the component indicators at the fourth level of the hierarchy. Each matrix is square, its size is determined by the number of components that are closed on each indicator.

The matrix also has the property of inverse symmetry, that is $f_{ZY} = \frac{1}{f_{YZ}}$.

Thus $f_{11} = f_{22} = \ldots = f_{yz}(y = z) = \ldots = f_{N_k N_k} = 1$ (N_k – the number of components that close on k–th indicator).

First, for each row of the matrix, the geometric mean is determined by the formula

$$\delta_y = N^k\sqrt{\prod_z f_{yz}}, y = \overline{1, N_k}; z = \overline{1, N_k}. \tag{8}$$

Then the normalization of the geometric mean (prioritization)

$$D_y = \frac{\delta_y}{\sum_y \delta_y}, y = \overline{1, N_k};$$
$$\sum_y D_y = 1; k = \overline{1, K}. \tag{9}$$

Numerical values of D_y are the coefficients of importance of the characteristics (Problems of improving, 2020).

Checking the consistency of local priorities is done in the same way as at hierarchy level five, using dependencies (6, 7).

The results of calculating local priorities for the fifth level of the hierarchy are the initial data for determining this indicator. The degree of satisfaction of the variants of technical means used to provide the material means is determined as follows: each column of vectors is multiplied by the priority of the corresponding characteristic and the result is compiled along each row. It should be noted that the areas of logistics activity (Figure 1) do not encapsulate all of the considered characteristics .

Therefore, it is possible for the k th direction of activity local priorities, which are determined by the formula (4), designate as $X_{iy}, y = \overline{1, N_k}; k = \overline{1, K}$. In our case K = 3.

Then the degree of satisfaction of the options of technical means in the k–th direction of activity are determined by formulas

$$\begin{aligned}
F(A_1)_k &= X_{11} \times D_1 + X_{12} \times D_2 + \ldots + X_{1y} \times D_y + \ldots + X_{1N_k} \times D_{N_k};\\
F(A_2)_k &= X_{21} \times D_1 + X_{22} \times D_2 + \ldots + X_{2y} \times D_y + \ldots + X_{2N_k} \times D_{N_k};\\
&- -\\
F(A_i)_k &= X_{i1} \times D_1 + X_{i2} \times D_2 + \ldots + X_{iy} \times D_y + \ldots + X_{iN_k} \times D_{N_k};\\
&- -\\
F(A_n)_k &= X_{n1} \times D_1 + X_{n2} \times D_2 + \ldots + X_{ny} \times D_y + \ldots + X_{nN_k} \times D_{N_k}.
\end{aligned} \tag{10}$$

Twenty-five matrices of pairwise comparisons of experts are formed at the third level of the hierarchy. These matrices contain evaluation or expert judgments about the relative importance of indicators at the third level of the hierarchy. Each matrix is square, its size is determined by the number of components that close on every second level. Accordingly, the correctness of the formulation of task and checking the judgment of experts is determined similarly to the fourth level.

At the second level of the hierarchy, one square matrix is formed, which has the property of an inversely symmetric matrix. In our case its size is determined by the number of areas of logistics (K).

The elements of the matrix contain evaluations or judgments of experts on the relative importance of indicators (directions of logistics) to meet the overall goal of the system. During the formation of the matrix, experts use the scale given in the work (Problems of improving 2020), and when involving a group of experts, the numerical value of the judgment is determined by the formula (2).

Geometric mean for each row of the matrix is determined by the formula

$$C_k = \sqrt[K]{\prod_{\nu} b_{k\nu}}, \nu = \overline{1,K}; k = \overline{1,K}. \quad (11)$$

Priorities are defined as follows

$$V_k = \frac{C_k}{\sum_k C_k}, k = \overline{1,K}. \quad (12)$$

Checking the consistency of local priorities at the second level of the hierarchy is done in the same way as at the fifth level of the hierarchy, using dependencies (6, 7).

The initial data for determining a rational alternative (the choice of technical means to provide military formations (units)) of the material means are the results obtained at the fifth and second levels of the hierarchy.

Degrees of satisfaction of options of maintenance of military formations (units) of the material means of the general purpose are defined by such formulas

$$\begin{aligned}
&S(A_1) = F(A_1)_1 \times V_1 + F(A_1)_2 \times V_2 + \dots + F(A_1)_k \times V_k + \dots + F(A_1)_K \times V_K;\\
&S(A_2) = F(A_2)_2 \times V_1 + F(A_1)_2 \times V_1 + \dots + F(A_1)_k \times V_k + \dots + F(A_1)_K \times V_K;\\
&-\,-\\
&S(A_i) = F(A_i)_1 \times V_1 + F(A_i)_2 \times V_2 + \dots + F(A_i)_k \times V_k + \dots + F(A_i)_K \times V_K;\\
&-\,-\\
&S(A_n) = F(A_n)_1 \times V_1 + F(A_n)_2 \times V_2 + \ldots + F(A_n)_k \times V_k + \ldots + F(A_n)_K \times V_K.
\end{aligned} \quad (13)$$

It is obvious that $\sum_i S(A_i) = 1$, $i = \overline{1,n}$. The maximum value $S(A_i)$ corresponds to a rational variant of the structure of the logistics system (rational alternative).

According to the works (Kotsyuruba V.I., Matsko O.Y., Chernykh I.V.; Problems of improving, 2020) to check the consistency of the whole hierarchy, the consistency index of each lower-level matrix is multiplied by the priority of the corresponding indicator of the next (higher) level of the hierarchy, according to which this matrix is composed. The obtained numbers are summed. The result is divided by an expression of the same type, but with random CI, which correspond to the size of each priority-weighted matrix. A consistency ratio of the whole hierarchy of less than 10% is considered acceptable. If this requirement is not met, it is necessary to improve the quality of expert judgment, or to review the structuring of the task.

One of the reasons for the unevenness of the expected deadlines for the planned volume of tasks is the irrational distribution of available logistics resources. Therefore, at the third stage there is a need for a rational allocation of resources to provide military units with material resources. The solution of the revealed discrepancy in practice becomes possible at the expense of application of optimization methods of decision-making which are applied to research of various problem questions (Fu M.C., Glover F.W., April J., 2005).

Rational distribution of logistical resources can be carried out using the method of the maximum element which allows in the presence of resource and time constraints to rationally distribute the available resource of forces and means for timely performance of the task (timely provision of military formations (units) with appropriate material means).

Accordingly, the initial data for the calculations are determined:

necessary volumes (quantity of material means and nomenclature, terms) of performance of tasks;

the available number of forces and means to perform logistical tasks to provide material resources;

restrictions on the scope of work;

priority in providing military formations with material resources.

The task is related to determining the optimal distribution of limited logistics resources (units, technical means of logistics operations) to perform tasks to provide material resources. It is necessary to find such distribution of forces and means of logistics on tasks at which success of performance of tasks as a whole will be the maximum, i.e. the maximum number of military formations (units) defining combat capability of grouping of armies will be provided with necessary material means (Problems of improving, 2020).

The main advantage of the maximum element method is that solving a problem with a large number of variables (n) leads to a sequential solution of n problems with one variable.

Accordingly, at each arbitrary step of the optimization process is the distribution of only one unit of discrete forces and means. This means that at each t–th iteration step ($t = 1,\dots,d$) is given a single increment ($\Delta X_i = 1$) only one i th variable of the optimal vector $X_0 = \{x_i^0\}_n$, which is a variant of the distribution of the same type of resource between n consumers. After a finite number of steps n, which is equal to the number of units of resource n, the entire resource is optimally distributed among consumers.

In the general case, the problem statement can be formulated as follows. It is necessary to find the optimal vector $X_0 = \{x_i^0\}_n$, which maximizes the objective function

$$F(X) = \sum_{i=1}^{S} F_i(x_i) = \sum_{i=1}^{S} A_i(1 - \varepsilon_i^{x_i}) \quad (14)$$

with linear constraints on its components

$$\sum_{i=1}^{n} x_i \le N \quad (15)$$

and additional conditions

$$\left.\begin{array}{l} x_i \in \{0,\ 1,\ \dots,\ N\}, \\ 0 \le (\varepsilon_i = 1 - \omega_i) \le 1, \\ A_i > 0, \end{array}\right\} \quad i = 1\dots S. \quad (16)$$

After opening the brackets in (14) we obtain:

$$F(X_0) = \max_X F(X) = \sum_{i=1}^{S} A_i - \min_X \sum_{i=1}^{S} A_i \varepsilon_i^{x_i} \sim \min_X \sum_{i=1}^{S} A_i \varepsilon_i^{x_i} \quad (17)$$

That is, the problem of maximizing the function (14) is equivalent to the problem of minimizing the function

$$\overline{F}(X) = \sum_{i=1}^{S} A_i \varepsilon_i^{x_i} \quad (18)$$

The problem statement can be formulated as follows. There are N of the same type of active units of technical means to perform tasks to provide material means. Each of them during the task of providing material means i–th ($i = 1,\dots,S$)of the consumer, which has a relative importance (weighting factor) A_j, provides him with material means with the probability $\omega_i = 1 - \varepsilon_i$. It is necessary to find such distribution of active means out of the provision of material means on consumers at which the total effect (total volumes, rate of performance of the task) will be the maximum. That is ω_i can be interpreted as a relative need and determined by the formula

$$\omega_i = \frac{W_i}{\sum_{i=1}^{S} W_i} = \frac{T_i}{\sum_{i=1}^{S} T_i} = \frac{V_i}{\sum_{i=1}^{S} V_i}, \quad (19)$$

where W_i – the required scope of the task of providing the *i*–th military formation (unit) with material means;

T_i – the time required to complete the task to ensure i th military formation (unit) of material means;

V_i – the required amount of task during the provision *i* th of the military formation (unit) with material means per unit time;

S – the total number of military formations (units) that need to be provided with material means.

Maximizing the overall effect $F(X)$ is equivalent to maximizing the value of the average value per one of the N means, that is

$$\max_X F(X) \sim \max_X \left\{\frac{F(X)}{N} = v(X)\right\}. \quad (20)$$

The average effect based on one of the N means $v(X)$ will be maximum if at each step of the process to assign one of the active means to the consumer i, where the increase in losses in this step (Δ_i)is maximum. Such an algorithm for the distribution of funds to consumers to achieve maximum effect can be considered justified, since each of the functions $F_i(x_i)$ is convex upwards and forms a descending sequence of increase of effect (Δ_i) from the influence of each subsequent means that is, it allows the distribution of funds in the same minimum (single) portions on one side and due to the similarity of funds does not require mutual replacement of any two of their units (Attetkov A., Galkin S., Zarubin V.).

$$F(x_i) = A_i(1-\varepsilon_i^{x_i}) = A_i\omega_i + A_i\varepsilon_i\omega_i + \ldots + A_i\varepsilon_i^{x_i-1}\omega_i^* == \Delta_{1i} + \Delta_{2i} + \ldots + \Delta_{x_i i} = \sum_{k=1}^{x_i} \Delta_{ki}$$

$$\Delta_{\mathrm{ki}} = A_i\varepsilon_i^{k-1}\omega_i \quad (21)$$

After highlighting the approach to solving the problem, it remains to determine the expression for calculating the value of the increment Δ_l of the objective function, which it receives at an arbitrary t–th step of the optimization process. By the time the t–th unit of funds is assigned at the t–th step of the process $(t-1)$units and the i–th military formation (unit) have already been distributed with some probability $P_i^{(t-1)}$ $(i = 1,\ldots,S)$,that is at this point the value of the objective function can be written

$$F_{t-1} = \sum_{i=1}^{S} A_i P_i^{(t-1)} \quad (22)$$

After assigning the t–th одиниці засобів l–th споживачу $(l = 1,\ldots,S)$the current value of the objective function will increase only by increasing the effect of the lth consumer and will be

$$F_t = \sum A_i P_i^{(t-1)} + A_l(1 - Q_l^{(t-1)}\varepsilon_l), \quad (23)$$

where $Q_l^{(t-1)} = 1 - P_l^{(t-1)}$ – the probability of not providing material means to the l–th consumer before the appointment of the t-th means;

$\omega_l = 1 - \varepsilon_l$ – conditional probability of its failure to provide material means t–th means.

Adding and subtracting from the right part of the formula (23) the term $A_l P_l^{(t-1)}$ and taking into account (22), we obtain

$$F_t = F_{t-1} + A_l(1 - Q_l^{(t-1)}\varepsilon_l) - A_i P_i^{(t-1)} \quad (24)$$

The gain that must be found after the elementary transformations will be written in the form

$$\Delta_l = F_t - F_{t-1} = A_l Q_l^{(t-1)}\omega_l = A_l^{(t-1)}\omega_l, l = 1,\ldots,S \quad (25)$$

If A_l – is the output weighting factor of the consumer, then $A_l^{(t-1)} = A_l Q_l^{(t-1)}$ – is its weight after the distribution $(t-1)$of the technical units.

To allocate different resource efficiency of technical means intended for the provision of material means using the proposed approach, technical means or support units should be divided into efficiency levels (productivity, capabilities) of the group. Resources should be distributed to consumers in groups. At the same time, the sequence of group changes should be carried out in the direction of reducing the efficiency (productivity, capabilities) of the means.

There may be situations when for all consumers the volume of the task must be performed not lower than permissible when it is obligatory to maximize the target function. The use of the given algorithm in such cases gives the chance to substantiate necessary quantity of technical means of delivery of material means for achievement of the purpose. In this case, the initial number of technical means N is not limited and the distribution of technical means continues until the total amount of tasks for all consumers would not satisfy the specified restriction. The number of technical means that ensures the achievement of the goal is taken equal to the number of distribution steps, that is $N = t$.

The experience of modern military conflicts has shown that the technical means of transporting material means have repeatedly been damaged or have been completely destroyed together with material means by means of fire destruction, as a result of a collision with engineering ammunition, etc. Under such conditions, for the timely provision of military formations (units) of material means at the fourth stage, the question arises in choosing a rational route of delivery of material means. The timely delivery of material means in military formations (units) will depend on the quality and timeliness of the decisions made regarding the choice of traffic routes for the delivery of appropriate material means.

That is, there is a need to determine the time of maneuver by technical means in the event of threats, taking into account the terrain, road conditions (the presence of paved roads, width of the roadway), finding out the presence of an extensive network of roads in a certain lane (area) and choose the most rational route maneuver during the emergence of threats (obstacles) during the task.

Accordingly, the initial data for determining the rational route of delivery of material means will be (Problems of improving, 2020):

the existing network of roads;

the number and characteristics of the calculated sections of the road network;

the composition of the column of the unit and the standard speed;

the predicted nature of threats on the route.

Substantiation of rational routes of movement of technical means of delivery of material means is carried out in two steps. In the first step it is necessary to determine the time of maneuver during the occurrence of obstacles, taking into account the possible threats in the settlement areas. In the second step it is necessary to choose a rational (most expedient) route of movement of technical means of transportation material means.

Determining the time of maneuver by technical means during hostilities, taking into account possible threats (obstacles) in the settlement areas, it is necessary to determine for the settlement sections of the network of roads that are within the maneuvers of the units during combat operations.

The expected time of maneuver on the j–th calculated section of the route of the road network in the lane of the i–th division can be determined by the formula

$$t_{\text{м}ji} = \frac{l_{ji}}{V_{ji}} + \sum_{k=1}^{K} t_{kji} \qquad (26)$$

where l_{ji} – length of the j–th sections of traffic, km;

V_{ji}– permissible speed on the j–th section of the road network, km / h;

t_{kji} – time spent to bypass k–th type threats (obstacles) on the j–th section of the road network, h.

The allowable speed on the j–th section of traffic can be determined as follows

$$V_{ji} = V_{\text{н}} \prod_{s=1}^{4} K_{sji} \qquad (27)$$

where $V_{\text{н}}$ – standard speed, km / h

$\prod_{s=1}^{4} \text{К}_{sji}$– the product of correction factors that take into account the characteristics of the area ($k_{\text{п}}$ – the intersection of the terrain; $k_{\text{дп}}$ – the quality of the road surface; $k_{\text{пр}}$ – roadway width; $k_{\text{гк}}$ – coefficient that takes into account the change in speed of technical means of transportation of material means from the depth of the column) (Kotsyuruba V.I., Matsko O.Y., Chernykh I.V.).

The time required to bypass the threats of the k–th type on the j–th section of the road network is calculated by the formula

$$t_{kji} = \frac{L_{kji}}{V_{kji}} \qquad (28)$$

where L_{kji} – the length of the route bypassing the threats that arise of the k–th type on the j–th section of the network of roads, km;

V_{kji} – speed of movement on j–th bypass k–th type of threats, km / h.

The expected length of routes to bypass the k–th type of threats on the j–th section of the road network can be determined by the formula, km

$$S_{kji} = N_{kji} \cdot l_k \cdot P_k \cdot \varepsilon_{kji}, \tag{29}$$

where N_{kji} – the available number of threats of the k–th type on the j–th section of the road network;

l_k – the estimated length of the area where there are threats of k–th type, km;

P_k – the probability of a threat of k–th type;

ε_{kji} – conditional probability of threats k–th type on the j–th section of the road network.

Regarding the implementation of the enemy's influence on the forces and means of logistics (technical means), it is possible to predict that on the roads there will be appropriate threats with a probability of up to 1. It remains to be seen what threats and to what extent may arise. The relative cost of resources for the creation of threats and their elimination is taken as an indicator by which the sequence of the threat's emergence is chosen

$$K_{wk} = \frac{t_{\text{в}k}}{t_{pk}} \tag{30}$$

where $t_{\text{в}k}, t_{pk}$– accordingly, the required cost of resources to create threats and their elimination k–th type. This parameter is used to determine the feasibility of sabotage, and so on.

Using the data presented in the work (Problems of improving, 2020) the probability of choice in order to establish of the k–th type of threats is defined as the ratio of the measure of relative resource costs to total resources

$$P_k = \frac{k_{wk}}{\sum_{k=1}^{K} k_{wk}}, k = 1 \ldots K \tag{31}$$

The conditional probability of the arrangement of threats of the k–th type on the j–th section of the network of roads is determined as follows

$$\varepsilon_{kji} = \frac{N_{kji} \cdot l_k}{\sum_{k=1}^{K} N_{kji} \cdot l_k}. \tag{32}$$

The choice of rational routes to bypass threats is proposed to be carried out using the method of dynamic programming.

The task is to choose a rational route of maneuver with the entire network of roads. To perform the maneuver, a network of paths in the lane and the values of partial indicators are taken, which are taken as the conditional length of the arcs of the graph. It is necessary to find such a route, the total length of the arcs of which will be the minimum fig. 2 (Problems of improving, 2020).

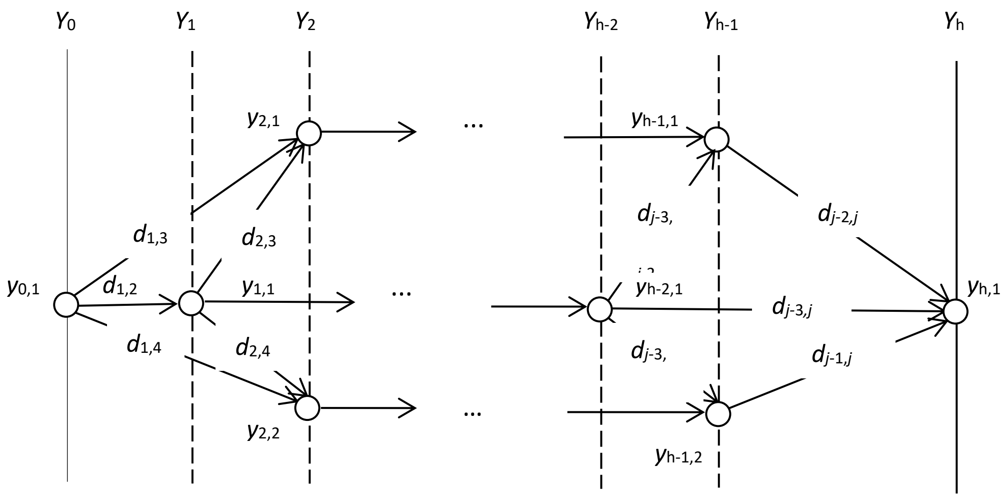

Fig. 2 – Scheme of problem formalization

The problem can be set as follows: between vertices $Y_{0,1}$ and $Y_{h,1}$ choose a route that gives the extreme value of the total weight of the arcs that form it. That is, find the smallest total length of the arcs d_{ij} between intermediate vertices of a network which characterize efficiency of realization of maneuverability of units. The expression is selected as the target function

$$D = \sum_j d_j \rightarrow min \quad (33)$$

The sequence of solving the problem is as follows:

At the first stage, moving from the next steps to the previous ones, at each step determine the control that provides optimal continuation of the process, i.e. conditional optimal control (Fu M.C., Glover F.W., April J., 2005). This continues until the first step of the process, in which conditional optimal control loses its conditional character and becomes unconditional optimal control;

the second stage of optimization begins with the first step, for which the found conditional optimal control becomes unconditional; it moves the system to a position for which conditional optimal control has already been found at the first stage, and is the optimal control for the second step.

The network of traffic paths must be divided into layers, determine the vertices of the graph (network nodes) and the length of the arcs (sections of roads); sequentially determine the potentials and choose the smallest for each vertex of the graph layers (conditional optimization stage); according to the total length of the arcs, a rational route of maneuver of units during combat operations is chosen.

The process of dividing the graph into layers is that the first layer Y_0 forms a vertex $\mathrm{y}_{0,1}$ – initial state. The vertex $\mathrm{y}_{0,1}$ and arcs (sections of routes) that come out of it are crossed out. On the remaining graph, determining the vertices that do not have arcs that are part of them. These vertices form a second layer. This procedure continues until the layer distribution of all vertices of the graph. The last layer forms the top $y_{n,1}$, that characterizes the final state (Biethahn J., Lackner A., Range M., Brodersen O., 2004).

Determination of potentials and selection of the smallest for each vertex of the graph layers (conditional optimization stage) is carried out by the formula

$$D = min\left\{d_{j_j} + D_{j-1}\right\}, j = 1 \dots J \quad (34)$$

where D – the potential of the next vertex of the graph;

d_j – the length of the intermediate arc;

D_{j-1} – the potential of the previous vertices of the graph.

Based on the results of calculations, we determine the optimal vector $D \in \langle d_{0,2}, d_{2,5}, \dots, d_{j-3,j-1}, d_{j-1,j} \rangle$ of arcs of the network of roads the vertices of which will form the nodes of the rational route of the maneuver.

At the fifth stage of evaluation of the implementation of logistics operations it is necessary to conduct a comparative analysis of technical means involved in the implementation of logistics operations (provision of material means).

Assessing the condition of technical means is to assess the level of their development in accordance with the classification. During the analysis it is necessary to consider the most important samples that determine the basic outline of this sort (type) of technical means and have the greatest impact on the nature of the tasks of logistics during the campaign (combat operations).

Comparative evaluation of similar samples of technical means of the logistics system and determination of prospects for their development will allow to determine complex quality indicators that take into account all existing properties of technical means; assess the compliance of domestic technical means with the tactical and technical requirements of troops and quantitative requirements of technical conditions and state standards, as well as compare domestic and foreign technical means (Dachkovskyi, V., 2019; Dachkovskyi, V., 2020).

The set of properties of technical means that determine their quality determines their suitability to meet certain needs of troops. Each of the properties is characterized by the corresponding tactical and technical characteristics (parameters). To compare the technical means of logistics, it is proposed to use the method of a progressive standard.

Assessment of the degree of conformity of technical means of logistics is carried out by comparison with the standard, for which there is no state standard and general technical requirements or quantitative indicators. Determination of requirement compliance is to compare the integrated quality indicator of the sample being evaluated with an integrated baseline indicator.

The initial data for the calculations is the technical characteristics of the technical means being compared (continuous operation time, weight, etc.).

For comparative evaluation it is necessary to choose a sample of technical means, which by functional features are divided into the same type of samples (further procedures will be carried out only between the same type of samples).

For the same type of technical means, it is necessary to establish a complete list of characteristics that reflect their properties, and to summarize the numerical values $\{A_{ij}\}$ – characteristics for each sample.

Evaluate the priority of the j–th characteristic (parameter). The ranking method is used to determine the priority of the characteristics (β_j).

Using the method of expert evaluations, a group of G experts is interviewed. Each of g–th expert determines the set of numbers C_{jg}, $j = \overline{1, J}$, which reflect their view on the priority of technical characteristics of technical means. Each expert must arrange the technical characteristics in the order of their importance and assign to each of them the numbers of the natural series: 1, 2, 3 so on. The rank of the indicator is determined by its number, if in its place in the series there are no others. When in one place we have several indicators that do not differ (have related ranks), the rank of each of them is equal to the arithmetic mean of their new numbers. Thus, the number of rank indicators is equal to R (Gurch L.M.; Litvak B.G.; Attetkov A., Galkin S., Zarubin V.; Asanov M. O.).

When determining the coefficients C_{jg} it is assumed that there is a linear relationship between the rank and the importance of the characteristics of technical means. Then the determination of the coefficients C_{jg} is carried out according to the formula

$$C_{jg} - 1 - \frac{r_{jg}^{-1}}{R}, \tag{35}$$

where r_{jg} – the rank of the appropriate j–th characteristic of technical means according to the g–th expert.

After that, the values C_{jg} are normalized

$$\beta_{jg} = \frac{C_{jg}}{\sum_{j=1}^{j} C_{jg}}; \ \sum_{j=1}^{j} \beta_{jg} = 1. \tag{36}$$

Finally, the value of the coefficients of importance β_j is determined by averaging the values β_{jg}, received from all experts. When the competence of experts in the group is considered the same

$$\beta_j = \frac{1}{G} \sum_{g=1}^{G} \beta_{jg}; g = \overline{1, G}. \tag{37}$$

The probability of the results of expert evaluation is characterized by the degree of consistency of assessments provided by experts. To do this, use the concordance coefficient (W), which is determined by formulas

$$W = \frac{12B}{G^2(R^3-R) - G\sum_{g=1}^{G} T_g}; g = \overline{1, G}, \tag{38}$$

$$B = \sum_{l=1}^{R} (\sum_{g=1}^{G} r_{lg} - \frac{1}{R} \sum_{l=1}^{R} \sum_{g=1}^{G} r_{lg})^2; l = \overline{1, R}, \tag{39}$$

$$T_g = \sum_{\varphi=1}^{H_g} (h_{\varphi g}^3 - h_{\varphi g}), \tag{40}$$

where T_g – indicator of related ranks in the g–th ranking. When matching (linked) ranks are missing, $T_g = 0$;

H_g – the number of groups of equal ranks in the g–th ranking,

$h_{\varphi g}$ – the number of equal ranks in the ϕ–th ranking group of related ranks during the ranking by the g–th expert.

The value of the concordance coefficient must be within $0 < W < 1$. Thus $W = 0$ means the complete opposite, and $W = 1$ – a complete coincidence of rankings. The probability is considered good when $W = 0{,}7 - 0{,}8$.

If the characteristics are considered equal in importance, the priority of each of them is determined by the ratio of the type $1/J$, where J – the total number of characteristics of the technical means that are evaluated.

For each characteristic the criterion rule according to which from all sample step by step choose the best (conditionally-reference) sample is established

$$A_{ej} = max\, A_{ij}\, , i = \overline{1 \ldots N} \qquad (41)$$

or

$$A_{ej} = min\, A_{ij}\, , i = \overline{1 \ldots N}\, , \qquad (42)$$

where A_{ij} – the absolute value of the j–th property of the i–th sample being compared;

A_{ej}– the absolute value of this property in the standard (base sample).

Then, we determine the relative personal performance of each sample for each characteristic, which for the properties of "more-better"

$$q_{ij} = \frac{A_{ij}}{A_{ej}}, \qquad (43)$$

and for "more-worse" properties

$$q_{ij} = \frac{A_{ej}}{A_{ij}}. \qquad (44)$$

For properties that are expressed as "exist" or "does not exist"

$$q_{ij} = \begin{cases} 1,\ A_{ij} \text{ - є}, \\ 0,\ A_{ij} \text{ - немає}. \end{cases} \qquad (45)$$

For any properties $q_{ij} = 1$, if $A_{1j} = A_{2j} = \ldots A_{nj} = A_{ej} \neq 0$.

Then, we determine the weighted average comprehensive quality indicator of each sample of technical means of logistics. The complex indicator of the i–th sample Q_i is determined by the formula

$$Q_i = \sum_{j=1}^{J} \beta_j\, q_{ij}, \qquad (46)$$

Where β_j – weighting factor$j$ th property (technical characteristics);

q_{ij} – relative unit index of the j–th property of the i–th sample.

The obtained values of the complex quality indicator of each sample relative to the largest value are normalized

$$К_j = \frac{Q_j}{max\, Q_j}. \qquad (47)$$

Then set the ranks of each sample of technical means of logistics by quality level. On the basis of which it is possible to draw a conclusion about the priority of the samples that were evaluated. Then it is necessary to identify the benefits and requirements for the characteristics that need improvement for existing technical means of logistics.

Conclusions

Thus, in the work on the basis of one of the components of the logistics system of the Armed Forces of Ukraine at the first stage the initial data are determined, at the second stage the hierarchy of the process of providing military formations (units) with appropriate material means is presented. An approach to the choice of technical means for the transportation of material means is also proposed. At the third stage the approach to rational distribution of technical means of logistics is offered and at the fourth stage the choice of a rational route of movement of technical means for delivery of material means. At the fifth stage, an approach to the evaluation of technical means involved in the implementation of logistics operations is proposed.

In the future, taking into account the study, it is necessary to assess the reliability and maintainability of technical means of the logistics system used in the Armed Forces of Ukraine.

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