Taxonomic approach to evaluating the logistics system of groups

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Abstract
The analysis of known approaches to assessing the effectiveness of the logistics system of the Armed Forces of Ukraine and other military formations suggests the lack of a unified and effective approach to assessing the effectiveness of the logistics system. However, given the large number of indicators for assessing the effectiveness of the logistics system, which are different in origin and physical content, there is an urgent scientific task of bringing these indicators to one unit of measurement. The task of evaluating the efficiency of the logistics system is reduced to a typical multi-criteria problem, which is proposed to be solved using a taxonomic approach. In this study, a taxonomic approach to assess the effectiveness of the logistics system is proposed. In the course of this study, the main indicators for evaluating the efficiency of the logistics system were determined, mathematical relations were proposed for evaluating the efficiency of the logistics system using a taxonomic approach, and the procedure for calculating the evaluation of logistics system failure using a taxonomic approach was proposed. The advantages of the proposed approach are its versatility and flexibility, which allows you to work with indicators that have different units of measurement by translating the indicators of the efficiency of the logistics system into dimensionless quantities; promptly add new indicators for assessing the effectiveness of the logistics system in the conduct of operations (combat operations) of groups of troops (forces). This approach is proposed to be used during the development of new information logistics systems, as well as as a separate information and calculation procedure in a single automated troop management system. A promising area of further research is the use of artificial intelligence to increase the efficiency of the logistics system of groups of troops (forces).

Key words: logistics system, state defense forces, efficiency, forms, methods.

Introduction

As the experience of military conflicts of recent decades shows, in modern conditions, the outcome of the operation (combat) largely depends on its quality, timeliness, and complete provision.

The volume of stocks of material resources, their separation, and the structure of support units must correspond to the purpose of the operation (combat), which is entrusted to the compounds, units, and subdivisions. This is also confirmed by the results of the annual Strategic Command and Staff Exercises (SSCS), which convincingly demonstrate that the logistics system is an important component for the effective conduct of hostilities (operations).

Material and methods

The issues of evaluating the efficiency of the logistics system are quite fully disclosed in a number of works, but each of them is devoted to the development of a certain direction of the logistics system of the Land Forces of the Armed Forces of Ukraine (Gorodnov V., Vlasyuk V., Ovcharenko V., 2017); Gorodnov V., Vlasyuk V., Ovcharenko V., 2016), which makes these approaches highly specialized and not universal for the study of other logistics systems. At the same time, the issues of the content and procedure for evaluating the efficiency of the logistics system during the preparation and conduct of the operation are debatable and need justification.

Given the large number of indicators for assessing the effectiveness of the logistics system of groups of troops (forces) there is an urgent scientific task of developing a taxonomic approach to assessing the effectiveness of the logistics system.

Results and discussion

One of the ways to solve multi-criteria problems is to choose one indicator as the main one and to limit other indicators. Thus, in the synthesis of the logistics system, the main indicator can be chosen as the continuity of supply of parts (units) of the group with material resources, for which the optimal structure is built, which maximizes this indicator. Other indicators, such as the cost of building a system for optimization, can be used as a constraint.

If you cannot choose the main indicator, and the reduction of indicators to a single gives an unacceptable error, then use the methods of multi-criteria optimization. In this case, first find the optimal structure of the logistics system for the main indicator, and then from this structure try to improve other indicators due to the allowable deterioration of the main. In practice, the task of selecting a rational version of the logistics system is associated with a comprehensive analysis of timeliness, completeness, continuity and cost. Timeliness is characterized by the probability of the event $P(t)$, when the delivery of material resources to the user is carried out no later than the established time t_{nes}:

$$P(t) = \begin{cases} 1, \text{if } t < t_{\text{nes}}; \\ \lambda \cdot e^{-\lambda \frac{t - t_{\text{nes}}}{t_{\text{nes}}}}, \text{if } t < t_{\text{nes}}. \end{cases} \quad (1)$$

Coefficient λ takes into account the conditions of hostilities by groups that change the steepness of the characteristics $P(t)$. This nature can be adjusted for specific operational situations, when a delay of, for example, several hours leads to disruption of specific combat missions. That is, the functional dependence (1) will be supplemented by additional restrictions. Reducing the amount of delivered material also reduces the effectiveness of combat use. Thus, the stock of fuel for fighters will not allow the set number of aircraft to rise into the air to perform the task of intercepting air targets, which reduces the calculated values of their efficiency by the appropriate amount.

This factor is characterized by an indicator of completeness of security $К_f$:

$$К_f = \frac{V_{sup}}{V_{\text{nes}}\text{nes}_{sup}} \quad (2)$$

where V_{sup} – the amount of material resources brought to the military unit (unit) for the period of preparation and conduct of hostilities;

V_{nes} – the amount of funds required to perform combat missions by the military unit (unit) during the preparation and conduct of hostilities by the group.

Continuity of tasks by units (subdivisions) of the group during the preparation and conduct of hostilities in the presence of material means is assessed by the formula:

$$k_{\text{cpi}} = \frac{t_{\text{cpi}}}{t_{\text{op}}}, \quad (3)$$

where t_{cpi} – the period of time when the ability to conduct the operation is provided *i*-thparts (subdivisions) of the group in the presence of material means delivered during the preparation and conduct of hostilities ($t_{\text{cpi}} \leq t_{\text{op}}$);

t_{op} – time of hostilities.

The value of this indicator is in the range [0,1], because $t_{\text{cpi}} \leq t_{\text{op}}$.

The total indicator of the continuity of hostilities of units (subdivisions) of the group during training is calculated by the formula:

$$k_{cp} = \frac{\sum_{i=1}^{n} k_{cpi}}{n}, \quad (4)$$

where n – the number of military units (subdivisions) of the group that are provided.

The criterion for the effectiveness of the logistics system of the group during the preparation and conduct of hostilities will be the following rule: $k_{cp} \to 1$.

Thus, the obtained set of indicators indicates the formulation of a multi-criteria problem of decision-making on the choice of a rational variant of the structure of the logistics system of the group. The solution to this problem is to cut off the options, obviously they do not meet one or more indicators. After such optimization, there is a limited set of satisfactory solutions for all indicators. The choice among the remaining options can be made using the taxonomic method.

The essence of the taxonomic method is that the desired variants of the structure of the logistics system of the group are characterized by the values of a set of indicators (timeliness, completeness, continuity and cost), constituting some multidimensional unit that can be represented as a vector in multidimensional space.

The dimension of this space will be equal to the number of n selected indicators. For example, let the values of coordinates of two vectors of values of indicators be known: that characterizing two variants of structure of system of logistics of grouping (points in the set space). Then the taxonomic distance between these points in multidimensional space is the value of r, which is determined (Gorodnov V., Vlasyuk V., Ovcharenko V., 2017); Gorodnov V., Vlasyuk V., Ovcharenko V., 2016) as follows:

$$r = \sqrt{\sum_{j=1}^{n} \left(g_{1j} - g_{2j}\right)^2}. \quad (5)$$

We assume that in this space the operations of the sum of vectors, multiplication by a scalar, scalar multiplication and metrization of space are introduced (Cartesian distance between two points is introduced). Then, since the components of any of the considered vectors are real numbers (from the physical content of the entered indicators), such a space will be a multidimensional Euclidean space.

Totality s variants of the structure of the logistics system of the group under consideration will be characterized by a matrix, each line of which specifies the corresponding vector – a set of values of indicators for a particular variant:

$$G = \begin{pmatrix} g_{11} & g_{12} & \cdots & g_{1j} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2j} & \cdots & g_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ g_{i1} & g_{i2} & \cdots & g_{ij} & \cdots & g_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ g_{n1} & g_{n2} & \cdots & g_{sj} & \cdots & g_{sn} \end{pmatrix}. \quad (6)$$

Such a matrix contains a complete description of the set of options under consideration, but usually indicators g_{ij}, which are part of the matrix, have different dimensions, describe different properties and different contribution to the efficiency of the logistics system of the group, so they cannot be compared. For further comparative analysis of variants of the structure of the logistics system of the group, it is necessary to make the transition to the centered dimensionless quantities, which have the form:

$$w_{ij} = k_j \frac{g_{ij} - M_j}{\sigma_j}, i = 1, \ldots, s;\ i = 1, \ldots, n, \quad (7)$$

where M_j – assessment of the mathematical expectation of the values of the indicator g_{ij}*i*-thvariant structure and *j*-thindicator value; k_j – importance factor *j*-thindicator, which is determined by an expert method; σ_j – estimation of the standard deviation of the values of the indicator g_{ij}.

The number of tests required to calculate the values of the required indicators, estimate their mathematical expectation and standard deviation are obtained in accordance with [6]. As a result, a matrix is formed *W* values of indicators, where all the elements w_{ij}have zero value of mathematical expectation and unit variance:

$$W = \begin{pmatrix} w_{11} & w_{12} & \cdots & w_{1j} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2j} & \cdots & w_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_{i1} & w_{i2} & \cdots & w_{ij} & \cdots & w_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_{n1} & w_{n2} & \cdots & w_{sj} & \cdots & w_{sn} \end{pmatrix}. \quad (8)$$

According to the introduced concept of taxonomic distance, we calculate estimates of this distance in pairs between all n vectors and construct a matrix *R* size $n \times n$, the elements of which at the intersection of the *i*-th row and *j*-th column become important:

$$r = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(w_{ik} - w_{jk}\right)^2}. \quad (9)$$

To form an indicator of the level of efficiency of the group logistics system, it is necessary to introduce the concept of a reference vector of indicator values. Then it is acceptable as the best option from the number of generated will be one for which the taxonomic distance from the reference vector will be less.

To find the vector of values for the reference version of the structure, it should be borne in mind that any indicator in terms of contribution to the overall efficiency of the variant structure of the logistics system can be such that positively affects the achievement of the goal of the group logistics system.

Such in taxonomy are called stimulants. It is desirable to have the value of this indicator as much as possible. The indicator can be such that it negatively affects the achievement of the goal of the group's logistics system, it is a disincentive. Then the best option for the structure of the logistics system of the group is the one for which the indicator becomes as small as possible.

If the indicator is positive when approaching an extremum (extremator – stimulator), then the best option is when the indicator acquires a value closer to the extreme. And when the indicator is negative, when the value of the indicator is approaching the extremum (extremator – destimulator), the best option is when the indicator acquires a value as far as possible from the extremum.

If the indicator belongs to the class of extremators and the value of the extremum is known, then the standardized dimensionless value of the optimal value of this indicator according to (Gorodnov V., Vlasyuk V., Ovcharenko V., 2016) is by the formula:

$$w_{ei} = k_j \frac{g_{ej} - M_j}{\sigma_j}, j = 1, \ldots, n. \quad (10)$$

To find the values of the reference vector according to each *j*-th indicator in the column of the matrix of standardized values of indicators (8) find the "best" value of the indicator w_{ej}among all indicators. Thus, the resulting vector of “best” values $W_e = (w_{e0}, w_{e1}, \ldots, w_{en})$ sets the point selected for the “standard of efficiency” of the structure of the logistics system.

But for practical use it is more convenient to have a normalized indicator of the distance from the reference vector to the vectors of the values of the indicators in the options under consideration. To find the distance to the reference vector r_{ei} mathematical expectations are calculated r_e and standard deviation σ_e:

$$r_{ei} = \sqrt{\sum_{j=1}^{n}\left(w_{ij} - w_{ej}\right)^2}, (i = 1, 2, \ldots, s);$$
$$\bar{r}_{ei} = \frac{1}{s}\sum_{i=1}^{s} r_{ei}; \quad \sigma_e = \sqrt{\frac{1}{s}\sum_{i=1}^{s}\left(r_{ei} - \bar{r}_e\right)^2}, \quad (11)$$

Given the multilevel (hierarchy), heterogeneity (diversity) of the group logistics system, the main criterion for assessing the effectiveness of the group logistics system will be the level of efficiency of the structure of the group logistics system.

The taxonomic method is formulated as follows:

1) determines the set of indicators that characterize the options for the structure of the logistics system of the group, as well as the coefficients of their importance;

2) *n* variants of structures of system of logistics of grouping are formed and values of these indicators are calculated;

3) the admissibility of the values of the calculated indicators is checked for each of the *n* variants of the structures of the logistics system of the group, as in the case of a negative result of the inspection are adjusted so as to reduce the values of indicators to those that are acceptable;

4) the values of the taxonomic indicator are calculated for each of the *n* variants;

5) the best option is selected according to the calculated value of the taxonomic indicator.

Conclusions

The development of indicators and criteria for evaluating the effectiveness of the group's logistics system has been developed. The proposed taxonomic indicator and the method of its calculation allow to compare the variants of the logistics system structure from the point of view of the set of indicators of the group logistics system considered in this article during preparation and operation taking into account linear and nonlinear influence of changes of such indicators.

This approach is proposed to be used during the development of new information logistics systems, as well as a separate information and calculation procedure in a single automated troop management system. A promising area of further research is the use of artificial intelligence to increase the efficiency of the logistics system of groups of troops (forces).

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