

*This paper considers elements of the methodology for the structural synthesis of the logistic support system of the Air Force grouping of the Armed Forces of Ukraine during the preparation for combat operations. Contradictions between the growing need for military units in material and technical means and the limited capabilities of the existing system of logistical support of the troop group predetermined the relevance and practical focus of this study.*

*Measures have been devised that affect the logistical support of the troop group. It is proposed to implement a mixed centralized-decentralized principle of building a logistics support system based on «material support clusters», which could ensure timely and complete delivery of material and technical means.*

*During the research, it was established that reducing the response time to changes in the volume of supplies of material and technical means in military units would ensure the continuity of the operation of weapons and military equipment, and this would give signs of the adaptability of the proposed logistics support system. It is theoretically justified that the use of the proposed methodology could affect the actual availability of established military reserves of the troop group and obstacles that prevent timely replenishment of daily expenses and losses. The remoteness of military units and separate units from provision agencies and the limited means of transporting material and technical means were taken into account. The calculations of the efficiency assessment of the developed structure of the logistic support system allow us to draw conclusions about its superiority over the existing one by 14–17 % by ensuring the continuity of combat operations.*

*The idea and elements of the devised methodology could be used in the calculations of transport tasks of civil enterprises*

*Keywords: hostilities, cluster, logistical support, material means, transportation, structural synthesis, troop grouping*

# PROCEDURE FOR THE STRUCTURAL SYNTHESIS OF THE LOGISTIC SUPPORT SYSTEM TO THE AIR FORCE GROUPING OF THE ARMED FORCES OF UKRAINE IN PREPARATION FOR COMBAT OPERATIONS

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Received date 07.06.2023

Accepted date 15.08.2023

Published date 31.08.2023

**How to Cite:** Gurin, A., Musienko, O., Khomik, M., Vavilova, N., Hurin, I. (2023). Procedure for the structural synthesis of the logistic support system to the air force grouping of the armed forces of Ukraine in preparation for combat operations. *Eastern-European Journal of Enterprise Technologies*, 4 (3 (124)), 73–84. doi: <https://doi.org/10.15587/1729-4061.2023.286324>

## 1. Introduction

Combat operations of the Air Force (AirF) group of the Armed Forces (AF) of Ukraine (AirF group) are conducted within the operations of the Armed Forces of Ukraine (repelling armed aggression, liquidation of armed conflict) and/or between them. In the course of preparing for the conduct of combat operations (CO), appropriate groups of troops are created in the Armed Forces of Ukraine.

The necessary level of combat capability of the AirF groups is created by timely providing them with a set amount of material and technical means (MTM), especially weapons and military equipment (WME), missiles and ammunition, fuel and lubricants (F&L), food, and military-technical property. Solving support tasks relies on the logistic support system (LS) of the Armed Forces of Ukraine [1–3].

One of the important tasks for LS of the AirF group is to transport MTM. It was planned to supply aircraft parts with aviation kerosene mainly by rail and pipeline transport but the experience of 2022–2023 shows that the main transport of military cargo is road transport.

During his speech at the NATO summit in Vilnius on July 11, 2023, NATO Secretary General Jens Stoltenberg told reporters that Ukraine faced the threat of ammunition depletion in the short term. For several months, the war has progressed to the stage of a war of attrition and a battle of logistics. According to Mr. Stoltenberg, Ukraine needs supplies of ammunition, spare parts, and fuel on a «huge scale» [4].

It is known that logistics is a fairly new scientific area in the structure of the Armed Forces of Ukraine, in connection with which the justification of the structure of the LS system of the Armed Forces of Ukraine is carried out without

sufficient consideration of models and methods of logistics. In the works by foreign authors, the main directions of the development of logistics support are considered. Those include Logistics Management and Strategy: Competing through the Supply Chain; Modern logistics; Strategic Logistics Management; Logistics Management and Strategy [5, 6].

It is believed that stocks are a kind of mechanism that adapts the parameters of material flows to the conditions of functioning of complex systems. Therefore, in order to build the structure of the LS system, it is necessary, first of all, to study the role and place of MTM in ensuring the grouping of AirF.

Contradictions between the growth of the need for MTM of military units and the limited capabilities of the existing LS system in terms of timely provision predetermined the practical orientation of this study.

Therefore, research aimed at devising a methodology for the structural synthesis of the system of logistical support to the grouping of the Ukrainian Armed Forces during preparation for combat operations is relevant.

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## 2. Literature review and problem statement

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Based on the results of a literature review of the experience of military conflicts of the millennium [7, 8], it is possible to conclude that CO management measures largely depend on the timely, complete, and high-quality provision of military units. The volumes of MTM reserves, their echeloning, and the structure of support units must correspond to the combat tasks entrusted to the military units of the Air Force groups. During the study, the tasks of routing and planning of vehicles were considered, which is a well-known approach to solving MTM transportation tasks. Such activities are usually summarized by the task of a traveling salesman.

Paper [9] reports the results of research entitled «The task of several traveling salesmen without collisions». Unlike the typical one, this task considers a special case where multiple vehicles can visit the same node to establish some actions. It is basically solved using the usual graph model consisting of a set of nodes and a set of edges. It is shown that such a graph model could be used to partially solve the problem of timely pickup of MTM. But questions remained unresolved because only information about the position of the transport is described. Paper [10] reports the results of research that focuses on finding the route and speed for the task of choosing the optimal route for a vehicle. But the issues related to the fact that this method uses the assumption of an independent choice of speed between any two edges remained unresolved. The reason for this may be impracticality due to the existence of speed restrictions during the movement of a military convoy. Work [11] shows the results of studies where a fleet of vehicles serves all nodes in an overlapping temporal packet. In our version, this task can only be partially applied, which makes relevant studies incomplete. In work [12], the results of the research «Tasks of traveling salesmen» are given. It is shown that the node is considered more as an area with a given radius, rather than as points. In addition, only one vehicle (convoy) is allowed on the area at any given time. But the questions remained unresolved, related to the fact that the travel time from node to node is assumed to be predetermined, and this assumption is practically impossible for this study. The reason for this can be various factors that affect the movement of the military convoy. In [13], the results of research are reported, where the «ant colony» algorithm is disclosed, which is applied to tasks

in the form of a graph and is used in the transport and logistics field. This approach is partially used in our work.

The issues of construction and assessment of the structure of LS system were studied in the works by specialists from the MTS of the Armed Forces and the National Guard (NG) of Ukraine. Work [14] reports the results of studies into the conceptual foundations of flow management in the system of LS of the Armed Forces of Ukraine. Work [15] presents the results of research into the problems of policy formation and operation strategy of the main types of provision of material resources of the Armed Forces of Ukraine. Work [16] reports the results of research on the consideration of the rear construction method in the operational area and the conceptual provisions of the theory of the rear support of the NG groups of Ukraine. It is shown that the modern issues of the formation of LS system are fairly fully disclosed in the cited works. However, the issues related to the specifics of maintaining the database of AirF group and the territorial dispersion of the troops remained unresolved. The reason for this can only be that the LS of combat operations of the AirF group has only its own peculiarities, which relate to the provision of parts of the military branches. An example of complexity can be the organization of LS combat use of radio engineering, anti-aircraft missile regiments and brigades, aviation command posts and aviation guidance points. The units of these military units are located in battle order at considerable distances from the support units of their military units and LS bodies (warehouses, bases, and joint support centers) of the operational level and the center.

Therefore, there is a problematic situation in which the process of searching for an option for the effective application of the AirF grouping is not always accompanied by obtaining a rational option for building the structure of LS system. The modern organization of LS system must prevent a decrease in the set value of CO efficiency indicators due to the timeliness and completeness of the targeted provision of military units.

Similar requirements are put forward in the leading countries of the world. At the same time, in the countries of the North Atlantic Alliance, logistics is being considered, the essence of which is the rational organization of the processes of the movement of military equipment, the provision of appropriate services from warehouses and bases of military equipment to military units [17, 18].

All this allows us to state that it is expedient to carry out a study aimed at improving the system of logistical support to the air force group, which implies devising a methodology for the structural synthesis of LS system of AirF group.

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## 3. The aim and objectives of the study

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The purpose of this study is to devise a methodology for the structural synthesis of the logistic support system in the Air Force group of the Armed Forces of Ukraine. This will make it possible to ensure the continuity of the availability of material and technical means during the preparation for the conduct of hostilities.

To achieve the goal, the following tasks were set:

- to work out conceptual solutions regarding the structural synthesis of the system of logistical support to the air force grouping;
- to build a mathematical model for calculating the average daily mileage of road transport for the logistical support of AirF grouping;

- to perform clustering of the distribution of the grouping of AirF;
- to assess the effectiveness of the structure of the system of logistical support to AirF grouping.

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#### 4. The study materials and methods

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The object of our study is the process of logistical support to the Ukrainian Armed Forces AirF grouping during the preparation for combat operations.

The formalization of a complex system in the form of subsystems (elements), which should represent three-element structures «node-function-object» (or NFO-elements), ensures the unity of functional and object decomposition. Therefore, it is an adequate and realistic way of representing the structure, composition, and functionality of a complex system.

A complex system formalized in this way is described by an adaptive (flexible, dynamic) alphabet, which has meaningful (but unambiguous) semantics and allows the implementation of a new procedure of analysis and research of complex military systems.

The analysis procedure consists of a number of stages:

- identification of nodes of connections in the structure of a complex system on the basis of functional connections of the system as a whole;
- detection of functionality that supports (ensures) detected nodes;
- determination of objects corresponding to the detected functionality.

The measures for conducting an analysis of the existing system of LS of AirF grouping, factors that affect the system, substantiation of indicators and criteria for evaluating the effectiveness of the system, are described in [19–22].

Changes occurring in complex systems can be formalized using graph models and graph-theoretic operations on graphs. Graph models, unlike models of the NFO type, consider a complex system in its nodal interpretation.

Graph structures are denoted as  $G=(V, E)$ , where  $V$  is the set of vertices corresponding to the elements of the complex system, and  $E$  is the set of edges corresponding to the connections between the elements of the complex system. It should be noted that in the structure of the graphs, connections between nodes can indicate arbitrary physical phenomena, as well as flows, including information flows, which are characteristic of the control system. The changes occurring in the structure of a complex system can be described in the form of graph-theoretic operations: contraction of an edge, removal (addition) of an edge, removal (addition) of a graph vertex.

*Research methods.* The methods of system analysis, observation, comparison, and generalization were used during the analysis of factors influencing the LS system of AirF group.

While devising the method of synthesis of the structure of LS system for the AirF group, the methods of synthesis, system analysis, operation research, graph theory, supply and distribution logistics were used.

During the description of the factors affecting the process of synthesis of the structure of LS system of AirF, the values of the coefficients of priority (importance) were calculated using the taxonomic procedure for determining the hierarchical sequence, as well as the importance weights of multi-dimensional objects based on the data of expert assessments for the case of solving the tasks of the structural synthesis of LS system for AirF group.

Decision-making methods, inventory logistics, methods of building decision-making support systems were used to form recommendations to management bodies.

In order to improve the structure of the logistics support system of AirF group, the main studies were carried out in the direction of the development of the methodology for the synthesis of LS system of AirF group, which consists of the procedure of structural synthesis and the procedure of parametric synthesis.

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#### 5. Results of research into the development of a procedure of structural synthesis of the logistic support system in the Air Force group

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##### 5.1. Conceptual decisions regarding the structural synthesis of the system of logistical support of the Air Force group

Fig. 1 shows the scheme of application of the procedure of synthesis of LS system for AirF grouping, which consists of the procedure of structural synthesis and the procedure of parametric synthesis.

At the first stage, structural synthesis is used, which determines the general description of the complex system. The use of this type of synthesis is expedient at the stage of direct preparation for conducting combat operations after receiving an order on LS of AirF group.

At the second stage, according to the structure designed, a parametric synthesis is performed, which consists of a set of algorithms, procedures, and features of the operation of LS system in AirF group.

The purpose of structural synthesis is to determine the structure of the object – the list of types of elements that make up the object, and the way the elements are connected to each other in the composition of the object. Parametric synthesis involves determining the work algorithms of both the entire system and its individual elements.

In the current paper, it is proposed to consider the procedure of structural synthesis of the system of logistical support to AirF group during preparation for the conduct of hostilities.

The necessary level of combat capability of AirF groups is created by providing them with a set volume of MTM in a timely manner. The solution of these tasks depends on the LS system of the Armed Forces of Ukraine.

Based on the study of the role and place of LS system in AirF group, the structural synthesis has a sequence of stages shown in Fig. 2. As can be seen from Fig. 2, the procedure of structural synthesis consists of the following models and partial procedures:

- a mathematical model for calculating the average daily mileage of automotive equipment (AT) for LS organization of AirF grouping;
- a partial methodology for substantiating the volume of MTM transport for the grouping of AirF, the results of which are used to determine the material provision (MP) cluster, calculate the location of the mobile field warehouse (MFW), and the need for AT;
- a partial procedure for dividing the grouping of Air Force into MP clusters, which is necessary for their determination and construction of the distributed LS subsystem for military units;
- a partial methodology for determining the rational location of MFW;
- a partial procedure for determining the composition of vehicles for the organization of delivery in the LS system of AirF grouping.

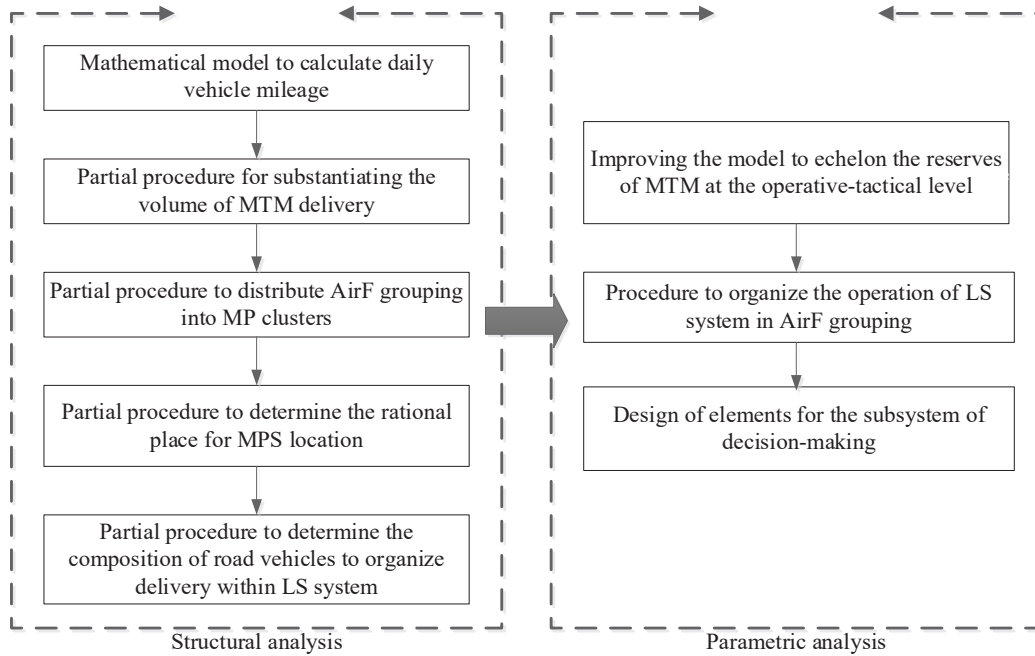


Fig. 1. Procedure for synthesizing the structure of the logistics support system to the Air Force of Ukraine

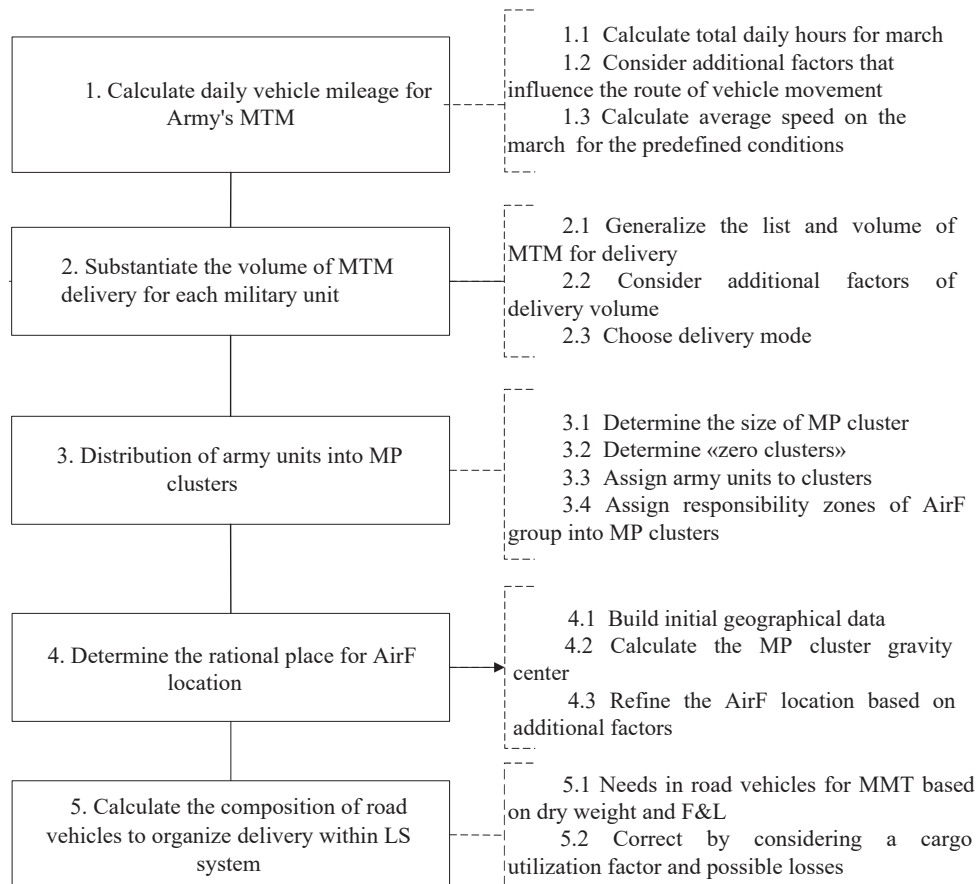


Fig. 2. Structural synthesis of the logistics system of the grouping of troops

**5.2. Mathematical model for calculating the average daily mileage of road transport for logistics support of the Air Force grouping**

The average daily mileage of road transport for MTM of the military units of the troop group is calculated according to the formula:

$$S_t = V_k \cdot t_p, \tag{1}$$

where  $V_k$  is the average speed of a vehicle convoy;  $t_p$  is the probable time of movement of the convoy per day.

The calculation of the probable time of movement of the convoy per day is carried out according to the formula:

$$t_p = 24 - t_{l/u} - t_{st} - t_{tm} - t_{dr}, \tag{2}$$

where  $t_{l/u}$  is loading/unloading time;  $t_{st}$  – time for stops;  $t_{tm}$  – time for technical maintenance of vehicles and special equipment;  $t_{dr}$  – driver’s rest time.

In turn, the loading/unloading time consists of:

$$t_{l/u} = t_{doc} + t_{sp} + t_{im.l/u}, \tag{3}$$

$t_{doc}$  – time for processing documents;  $t_{sp}$  – time spent in the queue to receive material resources;  $t_{im.l/u}$  – immediate loading/unloading time.

The analysis of the experience of the implementation of the specified measures made it possible to calculate the time:  $t_{doc} = 0.3–0.5$  h;  $t_{sp} = 1–2$  hours;  $t_{im.l/u} = 0.3–0.5$  hours.

Substituting the data into formula (1), we get:  $t_{l/u} = 1.5–3$  h;  $t_{st} = 3$  hours (scheduled after 3–4 hours of movement lasting up to one hour, in the second half of the daily transition a second stop lasting up to 2 hours). Day (night) rest areas are designated at the end of each daily shift;  $t_{tm} = 2–3$  hours (refueling of F&L and carrying out daily maintenance);  $t_{dr} = 6–8$  hours (sleep and eating). Substituting the data into formula (2), we get:  $t_p = 7–11.5$  hours.

According to the experience of the use of the Security and Defense Forces in the operation of the United Forces, it is known that for military roads (MR) on moderately rough terrain, the average speed of movement can be taken as 25–30 km/h. In mountainous, forested and marshy terrain and under other adverse conditions, the average speed of movement can be 15–20 km/h and lower. Under these conditions, the possible average daily mileage of vehicles with one driver is 150–200 km in the military sector (formula (1)). Such data correspond to the Unified List of Capabilities of the Ministry of Defense of Ukraine and the Armed Forces of Ukraine (capability code 5.3.1). During the movement of the convoy, there are additional factors of influence:

- the presence of roadblocks on the route (stops for mandatory document checks);
- zones of radiation pollution of the area (taking into account the delay time for taking measures after the enemy has used weapons of mass destruction (WMD));
- detours of the consequences of natural and man-made disasters after air and artillery strikes (expenditure of additional time for the movement of the motorcade);
- actions of the enemy’s diversionary and reconnaissance groups (DRG) during movement;
- condition of roads and traffic intensity (under conditions of absence of trained MR groups using road commandant units in a significant territory of the zone of responsibility, the need to use secondary roads, the speed of convoys decreases);
- the physical and geographical conditions of the region (the presence of bridges, tunnels, dams, and their destruction, mountainous, densely forested or marshy terrain contribute to the conditions of increasing the travel time).

These factors lead to a decrease in the average daily mileage of the convoy by 20...25 %. Thus, the average daily mileage of road transport for MTM troops of AirF group is 150...160 km. These values are accepted for further calculations in the methodology.

### 5.3. A partial procedure for dividing the Air Force grouping into clusters of material provision

In order to build a centralized-decentralized LS system for AirF group, taking into account the conditions of its im-

plementation, all military units must be divided into groups, each of which is provided with one MFW.

The area where these military units of AirF group are located is termed the MP cluster. The introduction of this concept «material provision cluster» is connected with the need to unify (group) military units based on the presence of a single MTS center. Within the cluster, it is possible to redistribute MTM between military units, which provides the property of adaptability, which ensures the continuity of CO. The dimensions of the cluster should correspond to the average daily mileage of vehicles, which carries the MTS of troops.

To formalize the problem, it is proposed to use graph theory and the method of cluster analysis [23–28].

Let’s introduce the notation:  $V$  is the set of vertices of the graph of the military units of the troop grouping;  $E$  is the set of edges of the graph corresponding to the distance (taking into account the actual distance according to the electronic map).

The combat order of AirF grouping is described by a graph of the form  $G(V; E)$ .

The scheme of implementation of the partial methodology for the distribution of troop groups by MP clusters is shown in Fig. 3.

A variant of the order of battle of the grouping of troops formalized by the graph is shown in Fig. 4.

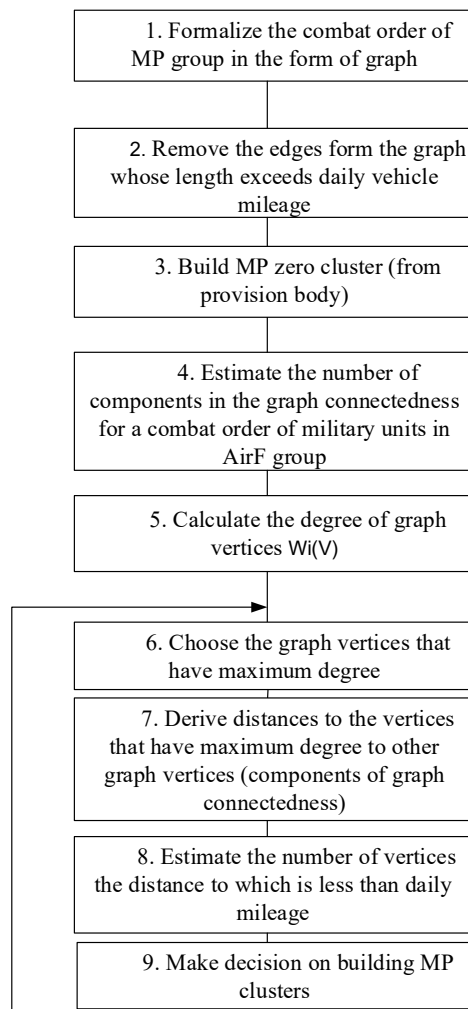


Fig. 3. Scheme of implementation of a partial methodology for the distribution of troop groupings by clusters of material provision

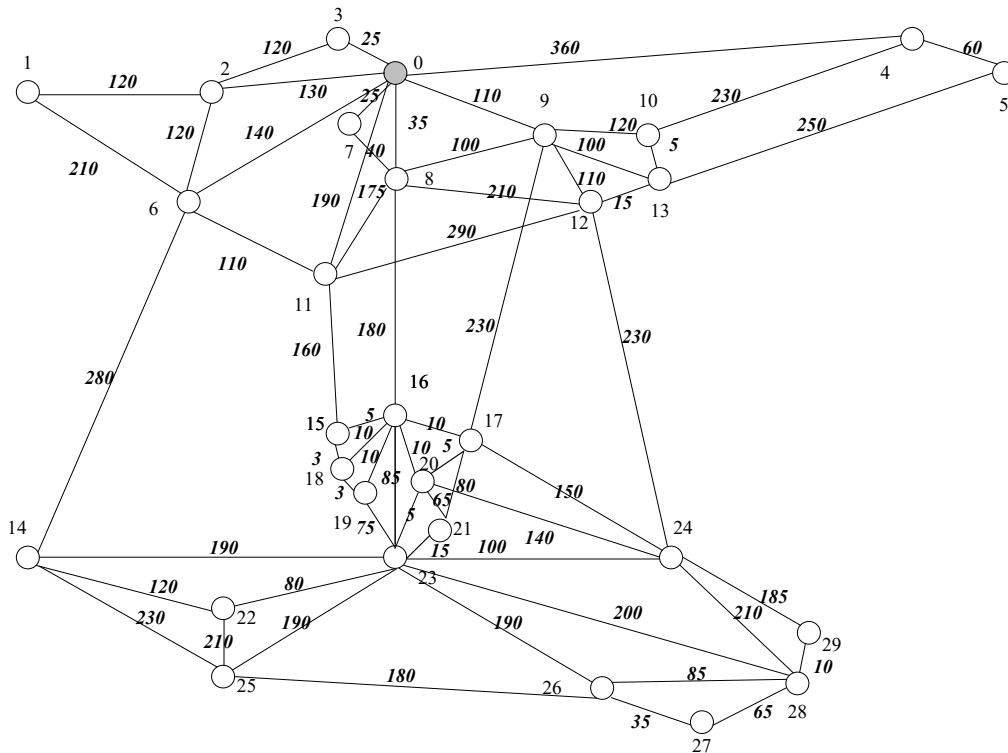


Fig. 4. Graph of the order of battle of the grouping of troops (option)

At the second stage of the partial procedure, the edges of the graph, the length of which exceeds the average daily vehicle mileage, are removed, as shown in Fig. 5. Removal of edges is carried out according to the rule:  $\forall E_i > S_i; E_i = 0$ . A new battle order graph is formed, which can be broken down into connectivity components. The incidence matrix of the graph also changes.

At the third stage, a zero cluster of MP is formed. This cluster includes military units that are at a distance of the average daily mileage of the armored personnel carrier to the support body and do not require the implementation of LS through the MFW. The construction of the null cluster is shown in Fig. 6.

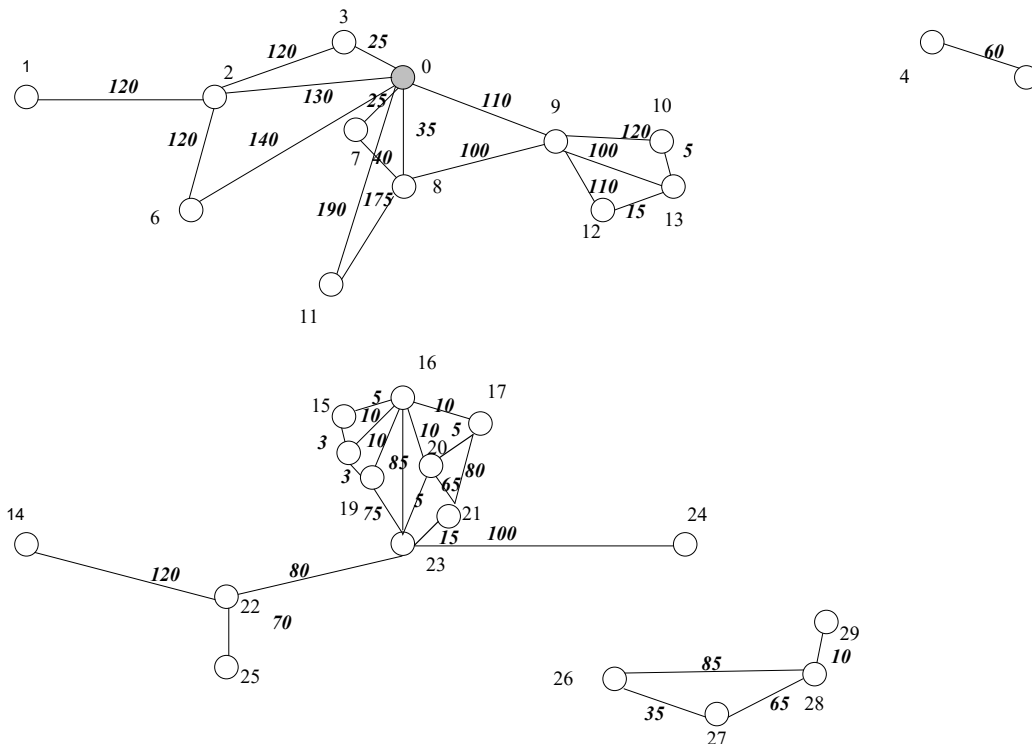


Fig. 5. Graph of the order of battle of the grouping of troops after removing the edges

As can be seen from Fig. 7, the original graph was split into three components of connectivity, for each of which it is necessary to select a cluster of MP. The analysis of the connectedness component of the graph is the task of the fourth stage of the partial procedure.

At the fifth stage of the partial procedure, the degree of the vertices of the graph is calculated, based on its incidence matrix, for the vertices that are not included in the zero cluster.

For example, the degrees of the vertices of the graph are given in Table 1.

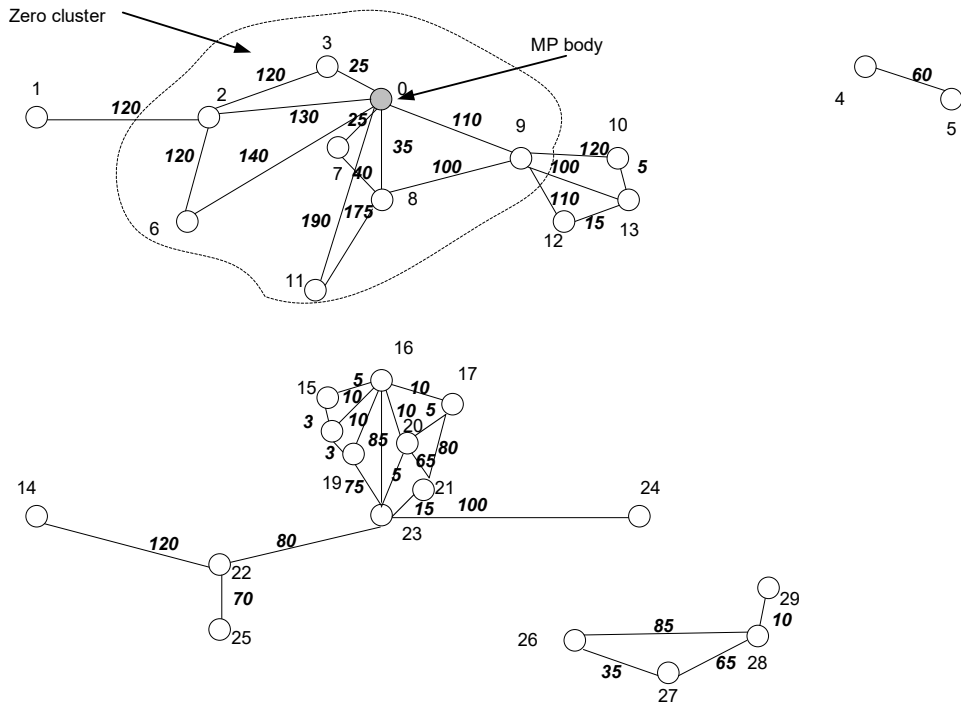


Fig. 6. Formation of a zero cluster of material provision

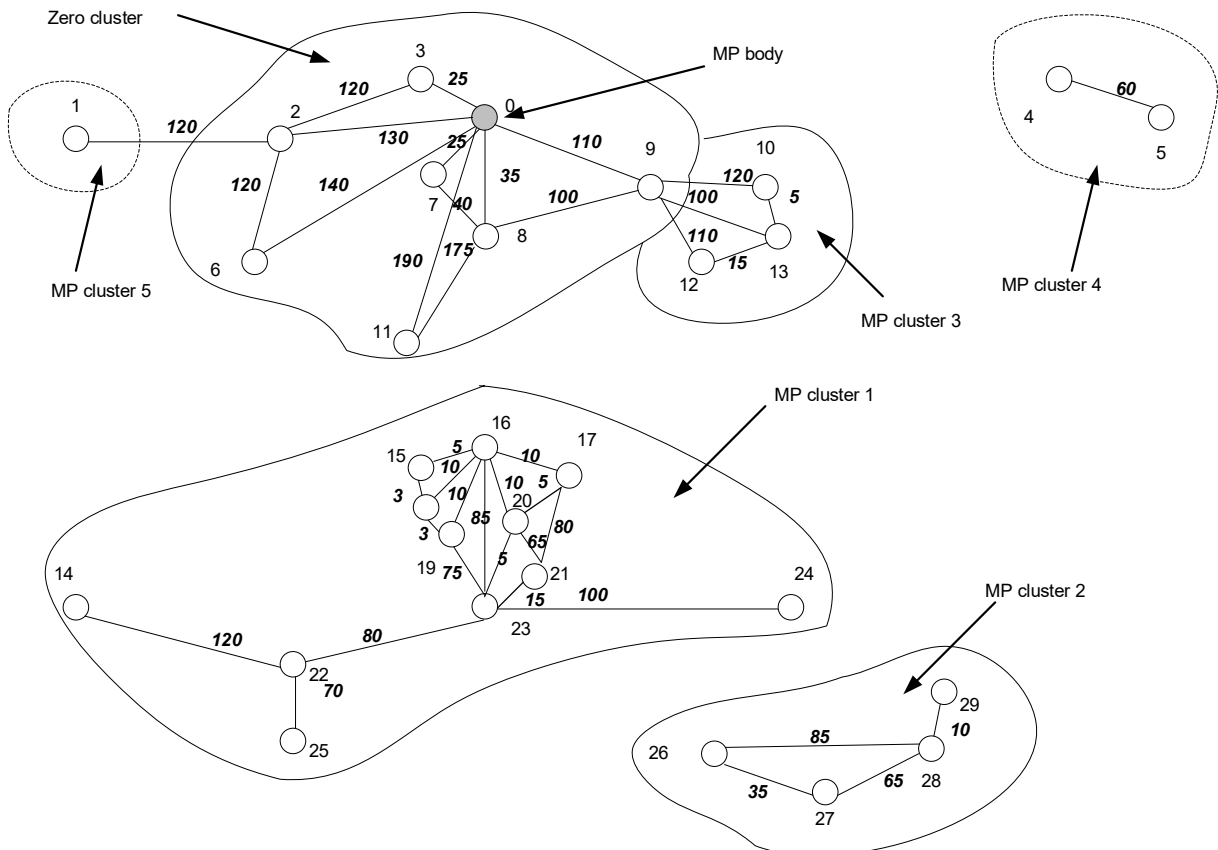


Fig. 7. Division of the grouping of troops into clusters

Table 1

Calculation of the degree of vertices of the graph and the number of military units, the distance to which is less than the average daily mileage of automotive equipment

The vertex number of the graph	Vertex degree	Number of military units	Cluster number
0	–	–	0
1	1	0	5
2	–	–	0
3	–	–	0
4	1	1	4
5	1	1	4
6	–	–	0
7	–	–	0
8	–	–	0
9	–	–	0
10	1	2	3
11	–	–	0
12	1	2	3
13	1	2	3
14	2	2	1
15	2	8	1
16	6	8	1
17	2	8	1
18	3	8	1
19	3	8	1
20	3	8	1
21	3	8	1
22	2	5	1
23	8	12	1
24	1	4	1
25	1	1	1
26	3	3	2
27	2	3	2
28	4	3	2
29	1	3	2

At the sixth and seventh stages, sequentially, starting from the vertex with the maximum degree, the distance to each vertex of the graph (components of the graph connectivity) is calculated to determine the grouping of AirF that can belong to one MP cluster.

At the eighth stage, the number of vertices is calculated, the distance to which is less than the average daily vehicle mileage; the result is summarized in Table 1. The sixth, seventh, and eighth stages are repeated for each component of the graph connectivity.

At the ninth stage, a decision is made regarding the selection of MP clusters based on the criterion of maximizing the grouping of AirF included in the MP cluster.

Fig. 8 shows the distribution of military units by MP clusters in accordance with Table 1.

The division of military units into MP clusters has a number of assumptions and limitations. The MP cluster, which has only one element in its composition, is usually a separate radar unit. For this cluster, MFW is not formed, and the MTP of the unit is carried out through MTM of the military unit from which this unit is assigned. In Fig. 8, such subdivision is vertex 1 of the graph, which is included in the fifth MP cluster. This cluster is not taken into account in the

further methodology, and the MTP of the subdivision is carried out through a subdivision (vertex 2 of the graph), which is included in the zero cluster.

For small units that are located at considerable distances from other military units in Fig. 8 vertices 4, 5 of the graph, it is expedient to provide additional allocation of forces and means for MFW of the neighboring (nearest) MP cluster. In this case, MFW is not formed for the MP cluster (Fig. 8, the fourth MP cluster).

To carry out the LS of AirF groups, which are included in MP clusters, MFW is created, which is an element of the military part of LS in the AirF group.

To determine the rational location of MFW in the MP cluster, the initial data should be:

- geographical coordinates of the location of the military units of AirF group and their units (objects) of MTP;
- volume of transportation of MTM.

After dividing the grouping of Air Force into MP clusters, with the help of a geographic information system (GIS), the geographical coordinates of the actual location of the military units and their sections (objects) of MTP (*X* and *Y*), to which MTM are planned to be transported via MTP, are determined on the map.

In order to improve the proposed methodology, the constituent elements in determining the rational location of MFW in the MP cluster were partially considered in [29, 30].

At the fifth stage of the implementation of the complex methodology, the calculation of the required number and composition of special and cargo vehicles for the military part of the logistical support to the air force group is performed.

The composition of road transport of units of the military unit of LS in the AirF group will consist of the total weight of the need for MTM and the distance from the support bodies to the military units and individual units. Probable combat losses and vehicle repairs are also taken into account.

In order to improve the proposed methodology, the constituent elements were partially considered in [31, 32].

**5. 4. Evaluation of the effectiveness of the desigend structure of the logistic support system for the Air Force group**

Evaluation of efficiency is carried out according to the methodology given in [33]. First, each of the *Q* desired control parameters is determined, which are characterized by their significance  $\alpha k$  (weight of the factor, priority when making a decision on the synthesis of LS system), the efficiency  $P_i(t)$  of calculating its value. All *Q* parameters have the same value of the efficiency indicator if they are calculated using the same information and calculation problem and the reliability *i* is the value of the procedure number.

Further, taking into account the need to have an estimate of the values of all parameters before the decision is made regarding the variant of the structure of the desired system, the value is calculated:

$$Y_i(t) = P_i(t) \cdot \sum_{k=1}^Q (a_k \cdot R_k), \tag{4}$$

which roughly characterizes the contribution of the procedure under consideration to the reduction of efficiency losses on all *Q* parameters and, thus, makes sense of the degree of expected completeness for the *i*-th procedure under consideration.

The generalized indicator of the efficiency of the procedure when compared with known one takes the form:



$$W(t) = \frac{Y_2(t) - Y_1(t)}{1 - Y_1(t)}, \quad (5)$$

where  $Y_1(t)$ ,  $Y_2(t)$  is the expected completeness of consideration of significant factors when using the first – existing (1) and the second – devised (2) procedures.

The described approach to the comparative evaluation of the effectiveness of various procedures was tested when solving a fairly large number of practical problems and showed its ability to give correct and satisfactory evaluations for practice.

The probability  $P(t)$ , which essentially determines the efficiency of obtaining a result with known restrictions on the available time  $t$  and the required time  $T$  (available time) for simulation or calculations, is defined as follows:

$$P(t) = 1 - \exp\left(-\frac{t}{T}\right). \quad (6)$$

The significance of  $\alpha_k$  factors is determined by the method of expert evaluations.

The devised methodology makes it possible to ensure the continuity of MTM presence during preparation for the conduct of hostilities. Fig. 8 shows the diagram of provision of military unit 1 for the existing LS system (option).

Analysis of calculations and data given in Fig. 8 allows us to conclude that there is no continuity of operation of WME of military unit 1 due to the presence of F&L. Thus, for 216 hours of hostilities, military unit 1 is not provided by the existing LS system for 106 hours by AB, and by DP for 60 hours. The continuity coefficient for the existing LS system is 0.72 according to DP and 0.51 according to AB.

Fig. 9 shows the calculation of the fuel reserves for military unit 1 for the designed structure of LS system in AirF group.

The coefficient of continuity for the designed structure of LS system in AirF grouping is 1.0 for DP and 0.88 for AB.

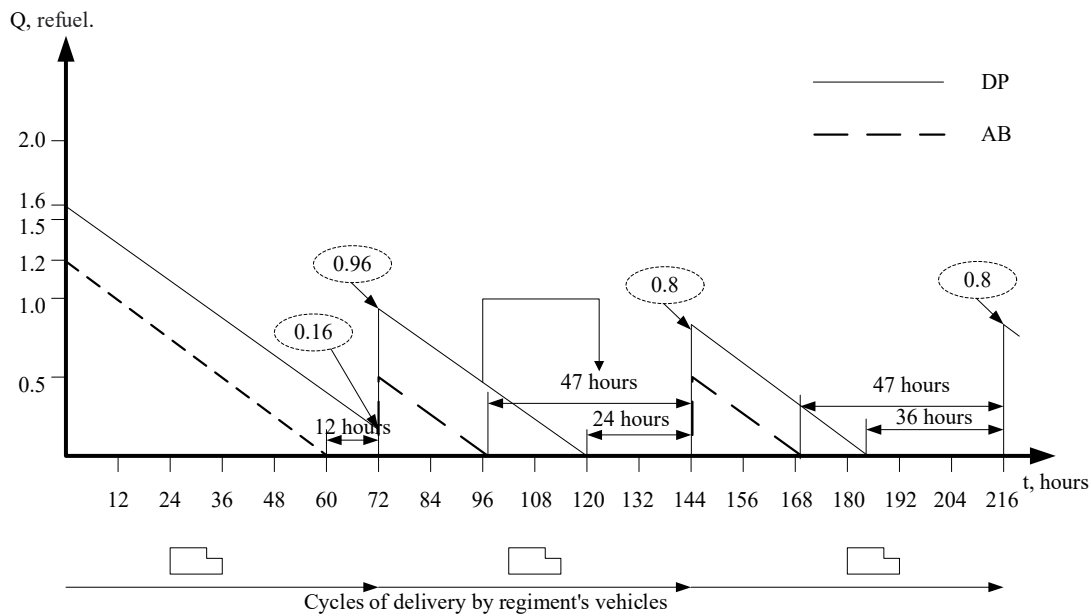


Fig. 8. Diagram of fuel delivery to military unit 1 for the existing logistics system

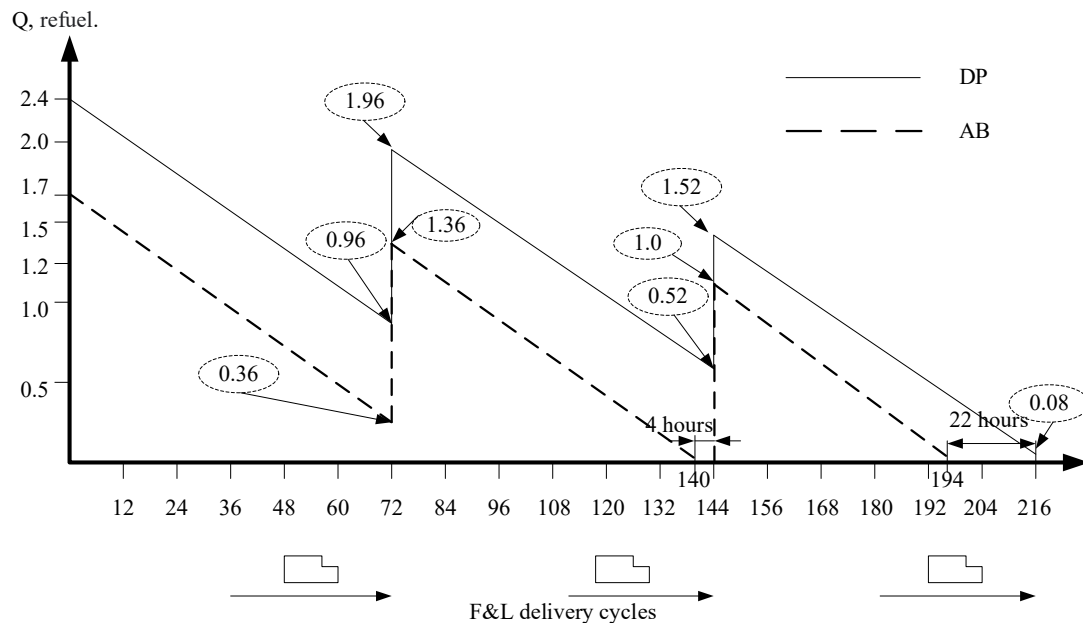


Fig. 9. The movement diagram of fuel stocks for military unit 1 by the devised logistics support system

In addition, schedules, calculations, justifications, and proposals for other military units were carried out under numbers 2–8.

Table 2 summarizes the generalized indicators of continuity for the considered military units for the existing and designed structure of LS system in AirF group during preparation for the conduct of hostilities.

Table 2

Generalized continuity indicators

No.	Military unit	Continuity indicator			
		Existing LS system		Devised LS system	
		DP	AB	DP	AB
1	Military unit 1	0.56	0.7	0.89	0.89
2	Military unit 2	0.43	0.45	0.84	0.91
3	Military unit 3	0.72	0.51	1.0	0.88
4	Military unit 4	0.68	0.45	1.0	1.0
5	Military unit 5	0.57	0.52	1.0	0.97
6	Military unit 6	0.57	0.51	0.86	0.97
7	Military unit 7	0.49	0.49	0.92	0.97
8	Military unit 8	0.56	0.56	0.89	0.89

The measure of the effectiveness of LS system functioning is the indicator of the continuity of tasks performed by the military units of AirF group based on the presence of MTM. The criterion for the effectiveness of LS system of the AirF group will be the approximation of this indicator to unity.

**6. Discussion of results of investigating the devised procedure of structural synthesis of the system of logistic support to troop grouping**

The peculiarity of the proposed methodology and our results in comparison with existing ones [14–16] is investigating various problems related to the improvement of the system of LS for AirF grouping.

A scheme of application of the procedure of synthesis of LS system for AirF grouping was built (Fig. 1). It consists of the procedure of structural synthesis and the procedure of parametric synthesis.

The role and place of LS system for AirF group were investigated. The sequence of stages of structural synthesis is shown in Fig. 2.

We substantiated the calculations of the average daily vehicle mileage for LS of AirF group (1). The calculation of the probable time of the movement of the military convoy per day was carried out (2). We estimated time for loading/unloading military cargo (3).

The scheme of implementation of the partial procedure for distributing the grouping of AirF by MP clusters is shown in Fig. 3. Fig. 4–7 demonstrate the distributed grouping of AirF into groups by MP clusters. The calculation of the degree of the vertices of the graph and the number of military units, the distance to which is less than the average daily mileage (160 km) of automobile equipment is given in Table 1.

The calculations performed to assess the effectiveness of the designed structure of LS system for AirF grouping ((4) to (6), Fig. 8, 9, Table 2) allow us to draw conclusions about its superiority over the existing one by 14–17 % due to ensuring the continuity of MWE.

The practical significance of our results is the possibility of direct use of the devised methodology and practical recommendations in the construction of LS system in the logistics management bodies at Air Force group.

At the same time, this study has limitations. Due to the fact that the largest number of transport vehicles of LS divisions in AirF group accounts for base trucks «Ural», the calculations were based on «AC-5.5-4320» bulk trucks and «Ural-4320» dry cargo trucks. In the future, it is advisable to equip automobile units with the latest models of foreign or Ukrainian production, for example: tank truck «AC-10-260», tank trailer «PC-9-8350», and «KrAZ-6322 (Soldier)», and trailer «KrAZ-A181V2». This will significantly reduce the number and size of car convoys, increase maneuverability, stealth, and other opportunities for delivery. The required amount of AT in bulk will be reduced by two times, and by dry cargo transportation – up to three times.

Thus, our results really make it possible to improve the system of LS in AirF grouping.

The procedure of synthesis of LS system of AirF group is the basis for improving the structure of the system of logistic support to AirF group. It consists of two areas of research. The current paper examines the procedure of structural synthesis of the system of logistical support of AirF group during preparation for combat operations. The second direction is the procedure of parametric synthesis, which is planned for consideration in subsequent studies.

The idea and elements of the devised methodology could be used in the calculations of transport tasks at civil enterprises.

**7. Conclusions**

1. A conceptual solution has been developed for the structural synthesis of the system of logistical support to AirF grouping. The peculiarity of this result, thanks to which it allows us to solve part of the general problem of the paper, is the construction of a scheme of application of the methodology of synthesis of LS system for AirF grouping. It consists of the procedure of structural synthesis and the procedure of parametric synthesis. Based on the study of the role and place of LS system in AirF group, a sequence of stages of structural synthesis was constructed. Their use in the work gives certain advantages over known results.

Based on the analysis of the existing system of LS for AirF group and the study of factors, it is known:

- a feature of the current system of the organization of LS of the Armed Forces of Ukraine is that the field divisions of the joint support centers are close to the front edge of the defense in order to provide priority support to the grouping of the Ground Forces;

- the specifics of the location of the military units of AirF group (on the territory of 7–8 regions) are not sufficiently taken into account in the work of the system of LS in the Armed Forces of Ukraine;

- supplies of MTM are delivered to individual radio technical units, mainly by the forces and means of their own brigades, and to aviation and anti-aircraft missile units by the forces and means of the «senior chief». Therefore, the probable interruptions in the delivery of MTM to military units do not fully satisfy the need for LS in AirF group, and this affects the increase in the loss of MWE and personnel.

2. A mathematical model for calculating the average daily mileage of road transport for LS of AirF group has been built. Its feature is the substantiation of the calculations of the average

daily vehicle mileage for LS of AirF group. Additional factors that have an impact during the movement of a military convoy under war conditions were taken into account, which made it possible to carry out calculations in a new way. The average daily mileage of road transport of AirF group is reduced to 160 km, the distance of transportation of MTM by transport of military units. The data correspond to the Unified List of Capabilities of the Ministry of Defense of Ukraine and NATO requirements.

3. The distribution of the AirF groupings of the Armed Forces of Ukraine into MP clusters has been completed. A feature of this result is the division of the AirF grouping into groups, each of which is provided by one MFW. The concept of «material provision cluster» was introduced, which is connected with the need to unify military units based on the presence of a single MTP center. Within the cluster, it is possible to redistribute MTM between military units, which provides certain advantages over known results and provides the property of adaptability, which ensures the continuity of CO management. The use of the proposed methodology will make it possible to ensure the flexibility of LS due to the mixed concentrated-dispersed principle of its construction; to timely provide a delivery of MTM for military units that have lost their means of transportation; to increase the survivability of military vehicle convoys during movement.

4. An evaluation of the effectiveness of the structure of LS system in AirF grouping was carried out. Conclusions were drawn regarding the effectiveness of the designed structure of LS system for AirF grouping. The advantages, due to ensuring the continuity of MWE operation over the existing system of LS in AirF group, amount to 14–17 %.

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#### Conflicts of interest

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The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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#### Funding

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The study was conducted without financial support.

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#### Data availability

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The data will be provided upon reasonable request.

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