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## MODELING OF SUPPLY LOGISTICS AND TRAINING OF MILITARY PERSONNEL FOR THE SUCCESSFUL USE OF WEAPONS IN A COMBAT AREA

The problem of multivariate nature is formed and solved, which is related to the modeling of logistics actions regarding various military equipment and weapons that enter the zone of military conflict. The relevance of the research is related to the comprehensive solution to the problem of the logistical nature of the supply and mastering modern various weapons by the military to create parity of forces in the military conflict zone. The current study creates a complex of logistic methods and models that allow analyzing training of the military, supply of weapons, ammunition and spare parts to the zone of military conflict, for the successful implementation of the goals of the military operation. This article analyzes the problem of using modern and diverse military equipment, which needs to be solved by systematically presenting military training in logistics, supplying various weapons from various manufacturers to the area of combat operations. The optimization model has been created to select and justify the composition of suppliers of weapons, spare parts and ammunition, in the context of risks that arise in the production and transportation of military cargo in a heterogeneous transport network. Optimization is performed in conditions of conflicting criteria: the number of new weapons; time and costs for the production and supply of military equipment; logistical risks. To study dynamic processes in the logistics of supplying weapons, spare parts and ammunition, a model has been created that allows, with the help of simulation agents, the investigation of the paths of movement of military cargo under the conditions of military threats and possible excitation of critical vulnerabilities in the heterogeneous transport supply network. An algorithm for forming the optimal delivery route at the minimum time under risks has been developed. Simulation modeling is used to estimate the movement time of military cargo, delays in supply, accumulation of risks in cargo transportation, consequences of threats and vulnerabilities in supply logistics, etc. This study examines the process of training the military by mastering new competencies for the use of various modern weapons in combat conditions. Simultaneously, the short terms of training of military personnel and the logistics of their transportation to training centers are considered subject to the threats and risks of wartime. The effectiveness of the proposed approach is ensured by a systematic representation of the logistics of supplying various weapons, spare parts and ammunition to the conflict zone, and a comprehensive solution to the research tasks set. The scientific novelty of the conducted research is associated with the development of new methods and models based on system analysis. The following methods were used: simulation modeling, models for optimizing, competence model for acquiring new knowledge by the military personnel. The results of the study should be used to select and justify suppliers of new diverse weapons and military equipment, train the military to use modern kinds and types of weapons, plan routes and schedules for the supply of military cargo to the area of combat operations, in conditions of wartime threats.

**Keywords:** combat area; supply logistics; threats and critical vulnerabilities; various military equipment; weapons suppliers; military competencies; agent simulation modeling; optimization.

### Introduction

Establishment of military parity of forces in a combat zone requires the use of various kinds and types of weapons, which are supplied by different manufacturers in different countries of the world. This causes great logistical difficulties and leads to problems related to the effective use of various kinds and types of weapons in the zone of military conflict. The analysis conducted by military specialists on the use of various military equipment revealed the following issues, that aren't

sufficiently covered in papers on the topic of this article:

1. Small batches of various weapons coming from different suppliers to the zone of military conflict. The existing papers don't consider a diversity of sources for the supply of various military equipment [1, 2].

2. Difference in ammunition that comes from different suppliers and which can only be used for specific types of weapons. In the papers, this problem isn't considered in detail [3, 4].

3. Insufficient number of spare parts and repair kits or unsatisfactory number of spare parts supplied sepa-

rately from weapons. This problem isn't considered in published sources [5, 6].

4. Difficulties associated with the repair of military equipment and routine maintenance in the zone of military conflict. In existing papers, the issue of remoteness of military equipment repair bases isn't reflected in detail [7, 8].

5. Necessity to conduct short-term training of the military to acquire knowledge using various kinds and types of new weapons. The problem of accelerated military training of military personnel in a short time with the conditions of military threats isn't considered in existing papers [9, 10].

6. The problem associated with long logistics supply chains of weapons and military equipment [11-13], in conditions of threats of martial law [14, 15], in a heterogeneous transport network with transshipment, temporary storage and storage of military cargo. In existing papers, the issues of supplying military equipment in the conditions of a heterogeneous transport network and military threats aren't reflected [16, 17].

The analysis of existing research on the topic of this article showed that there is no systematic representation of the logistical problem of supplying military equipment to the zone of military conflict. Insufficient attention has been paid to the impact of military threats on logistics chains with critical vulnerabilities of transport systems. The papers don't consider the modeling of military competencies, which are necessary for mastering various modern weapons [18-20].

Hence, the relevance of the topic of the proposed publication. The paper considers the modelling of a complex of logistical actions related to the supply, mastering and use of various kinds and types of modern weapons in the area of combat operations.

There is a contradiction between the need to establish military parity of forces in the area of combat operations, due to the use of modern diverse weapons, and the failure of existing methods of studying the logistics processes of supplying, mastering and effective use of military weapons in the area of combat operations, which is eliminated in this research paper.

The research aims to create a complex of methods and models that will allow planning the supply of weapons, spare parts and ammunition to the zone of military conflict, and the military training for the use of modern weapons. In accordance with the established purpose of the study, it is necessary to solve the following tasks:

1. Analysis of supplies of various weapons from different manufacturers to the zone of military conflict.
2. Create an optimization model to justify and select suppliers of military equipment.
3. Develop a simulation model for studying the logistics supply chains of military equipment.

4. Form a set of military competencies required to use new systems weapons.

5. Provide an example of choosing the composition of competencies to use a new combat system.

### **1. Analysis of supplies of various weapons from different manufacturers to the zone of military conflict**

Further, a systematic representation of logistics processes will be formed, which are related to the supply of various kinds and types of weapons to the zone of military conflict in order to establish military parity of forces.

Fig. 1 shows a diagram of the logistics process of supply, which includes the supply of the main components of weapons by manufacturers: weapons; ammunition; spare parts.

Suppliers of various kinds and types of military equipment may be located in different countries and at a long distance from the conflict zone. As an example, it can be cited the geography of suppliers of various artillery weapons: M777 towed howitzers (USA, Austria, Canada), self-propelled howitzers (Caesar (France), Panzerhaubitze (Germany), M109 (USA), AHS Krab (Poland)).

Spare parts suppliers have limited capacity in terms of production and delivery volume (small batches).

Ammunition is not always interchangeable, so it can only be used for specific kinds and types of weapons. For example, different calibers 105, 152, 155.

Spare parts and repair kits are not always delivered in the right quantity along with weapons and military equipment. The lack of spare parts can lead to the decommissioning of weapons in the conflict zone. To repair military equipment, it is necessary to send it to the weapons manufacturer.

Supply logistics is carried out in long logistics chains of a heterogeneous transport network (aviation, railway, road, sea modes of transport), which leads to transshipments from one transport route to another, as well as temporary storage of military cargo.

This nature of the logistics of supplying weapons, spare parts and ammunition to the area of combat operations leads to the following:

- long tangled logistics supply chains;
- occurrence of delays when moving across state borders and switching from one mode of transport to another;
- occurrence of delays related to the temporary storage of weapons and military equipment;
- emergence of threats to the transportation of military cargo related to the actions of the aggressor;

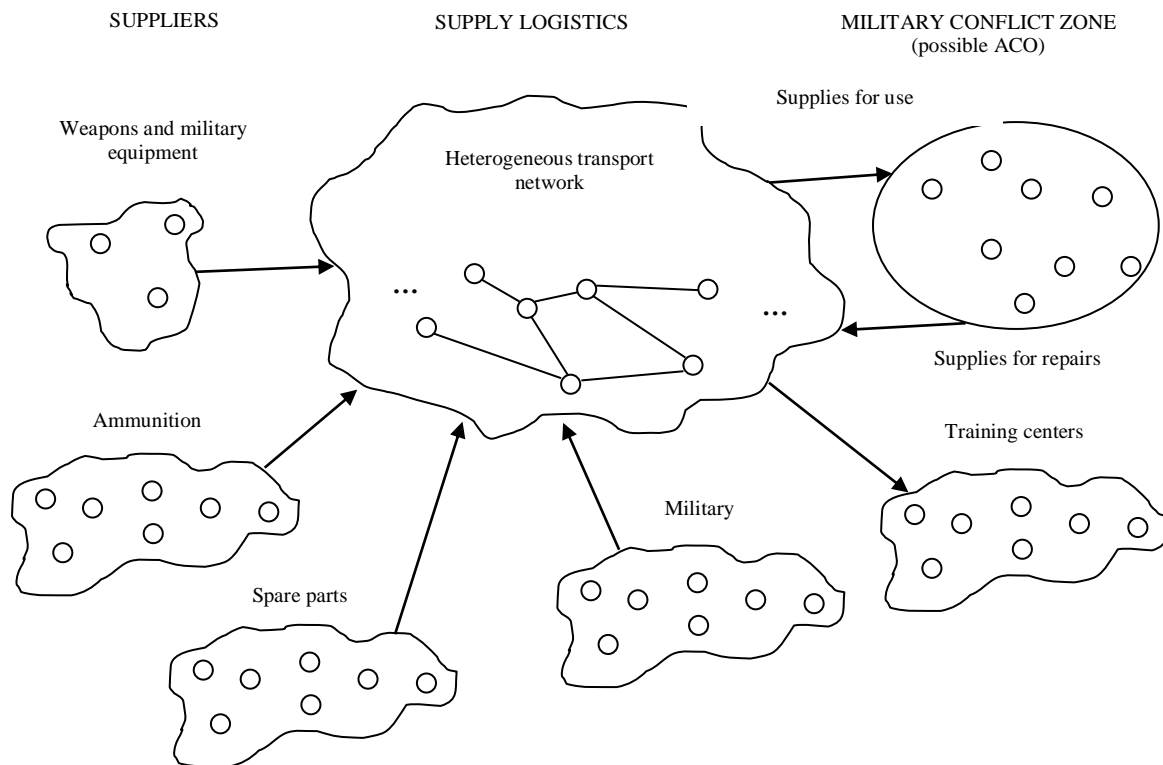


Fig. 1. Logistics scheme for the supply of weapons and military equipment

- necessity to assess the risks that arise in elements of a long logistics supply chain in wartime. In case of breakdowns and failure of weapons, there are difficulties in repair, which requires specialists who are not in the area of combat operations. Therefore, it is necessary to transport damaged military equipment to manufacturers located at a great distance from the zone of military conflict.

In addition to the logistical problems of supplying weapons and military equipment, there is the problem of the military's assimilation of new, diverse kinds and types of weapons in wartime conditions. The solution to this problem is related to the accelerated training of military personnel in training centers. In the course of training, it is necessary to add new, special competencies to the existing basic competencies of the military, which are related to modern kinds and types of weapons to be used in the zone of military conflict. At the same time, it is necessary to carry out logistical actions related to the transportation of military personnel to training centers in the face of wartime threats.

Thus, a systematic representation of logistics actions for the supply of weapons and training of the military for their use is formed, which is the basis for solving the problems of the proposed study.

## 2. Development of an optimization model to justify and select suppliers of military equipment

The formation of multiple suppliers of weapons, ammunition and spare parts to create military parity of forces in the conflict zone requires analyzing the capabilities of each of the suppliers and taking into account logistics actions related to the transportation of military cargo in the face of wartime threats. To assess the capacity of manufacturers of weapons, ammunition and spare parts, it is necessary to take into account the formation of groups of suppliers of the same kind and type of weapons, because one supplier cannot supply the required amount of weapons due to limited production capabilities and financial conditions that are associated with the formation of new defense orders. The formation of a set of possible compositions of the group of suppliers for the  $i$ -th kind and  $j$ -th type of weapons is a combinatorial task of sorting through the options, taking into account the limited capabilities of each weapons manufacturer. Assume, as an example, military specialists (experts), after analyzing manufacturers for the  $i$ -th kind and  $j$ -th type of weapons, three possible suppliers of weapons were identified. Then, the number of possible variants for the composition of suppliers in the group of suppliers for  $n=3$  will be  $K=2^n-1=7$ . For  $n=3$ ,

all variants of the composition of weapons suppliers in the supplier group can be conditionally represented as:

1. 001
2. 010
3. 011
4. 100
5. 101
6. 110
7. 111

where 1 corresponds to engagement of the manufacturer to the supplier group; 0 — to no engagement.

Here, the variant 1 corresponds to engagement of only one third possible weapons supplier to the supplier group, the variant 3 corresponds to engagement of the second and third suppliers, whereas the variant 7 corresponds to engagement of all weapons suppliers.

Integer (boolean) variable  $x_{ijk}$  are introduced, which takes the following values:

$$x_{ijk} = \begin{cases} x_{ijk} = 1, & \text{if for } i\text{-th kind of weapons} \\ & \text{of } j\text{-th type the } k\text{-th variant of composition} \\ & \text{of suppliers group is selected;} \\ x_{ijk} = 0, & \text{in another case,} \end{cases}$$

where  $\sum_{k=1}^{P_j} x_{ijk} = 1$ , which means mandatory selection of a specific group of suppliers for the  $i$ -th kind and  $j$ -th type of weapons,  $P_j$  is the number of possible variants for suppliers of the  $j$ -th type of weapons.

The following indicators for evaluating options for the composition of a group of suppliers are introduced:

$N$  is the number of weapons to be sent to the zone of military conflict:

$$N = \sum_{i=1}^M \sum_{j=1}^{m_i} n_{ij},$$

where  $n_{ij}$  is the number of weapons of the  $i$ -th kind and  $j$ -th type to be used in the zone of military conflict;

$m_i$  is number of types of weapons of the  $j$ -th kind;

$M$  is the number of kinds of weapons used in the zone of military conflict.

Given the variable  $x_{ijk}$ , the following is obtained:

$$n_{ij} = \sum_{k=1}^{P_j} n_{ijk} x_{ijk},$$

where  $n_{ijk}$  is the number of weapons of the  $i$ -th kind and  $j$ -th type to be supplied by the  $k$ -th variant of the composition of the group of suppliers;

$T$  is the time spent on the production and logistics of transporting weapons to the zone of military conflict:

$$T = \sum_{i=1}^M \sum_{j=1}^{m_i} t_{ij},$$

where  $t_{ijk} = t'_{ijk} + t''_{ijk}$ ;

$t_{ijk}$  is the time costs associated with the production and logistics of delivery of the  $k$ -th variant of the group of manufacturers of the  $i$ -th kind and  $j$ -th type of weapons;

$t'_{ijk}$  is the production time of a batch of weapons of the  $i$ -th kind and  $j$ -th type of weapons of the  $k$ -th composition of manufacturers;

$t''_{ijk}$  is the time spent on logistics of transportation of a batch of weapons of the  $i$ -th kind and  $j$ -th type of weapons of the  $k$ -th composition of manufacturers.

Given  $x_{ijk}$ :

$$t_{ij} = \sum_{k=1}^{P_j} (t'_{ijk} + t''_{ijk}) x_{ijk}.$$

$W$  is the expenses for the production and supply of weapons:

$$W = \sum_{i=1}^M \sum_{j=1}^{m_i} w_{ij},$$

where  $w_{ijk}$  is costs of production and logistics of supply of weapons of the  $i$ -th kind and  $j$ -th type for the  $k$ -th variant of the supplier composition:

$$w_{ijk} = w'_{ijk} + w''_{ijk},$$

where  $w'_{ijk}$  is the expenses for the production of weapons of the  $i$ -th kind and  $j$ -th type for the  $k$ -th variant of the supplier composition;

$w''_{ijk}$  is the logistics costs for the supply of weapons of the  $i$ -th kind and  $j$ -th type for the  $k$ -th variant of the supplier composition.

Then, given  $x_{ijk}$ :

$$w_{ij} = \sum_{k=1}^{P_j} (w'_{ijk} + w''_{ijk}) x_{ijk}.$$

R is the risks of production and supply of weapons to the zone of military conflict:

$$R = \sum_{i=1}^M \sum_{j=1}^{m_i} r_{ij},$$

where  $r_{ijk}$  is the risks of supplying the  $k$ -th variant of the supplier composition of the  $i$ -th kind and  $j$ -th type of weapons:

$$r_{ijk} = r'_{ijk} + r''_{ijk},$$

where  $r'_{ijk}$  is the production risks of the  $i$ -th kind and  $j$ -th type for the  $k$ -th variant of the supplier composition;

$r''_{ijk}$  – logistics risks of delivery of the  $i$ -th kind and  $j$ -th type for the  $k$ -th variant of the supplier composition:

$$r_{ij} = \sum_{k=1}^{P_j} (r'_{ijk} + r''_{ijk}) x_{ijk}.$$

Taking into account all kinds and types of weapons to be sent to the zone of military conflict, the following presentation of indicators for evaluating possible weapons suppliers will be obtained:

$$N = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} x_{ijk},$$

$$T = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (t'_{ijk} + t''_{ijk}) x_{ijk},$$

$$W = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (w'_{ijk} + w''_{ijk}) x_{ijk},$$

$$R = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (r'_{ijk} + r''_{ijk}) x_{ijk}.$$

To ensure military parity of forces in the military conflict zone, it is necessary to:

$$\max N, N = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} x_{ijk},$$

subject to the following restrictions:

$$T \leq T', T = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (t'_{ijk} + t''_{ijk}) x_{ijk},$$

$$W \leq W', W = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (w'_{ijk} + w''_{ijk}) x_{ijk},$$

$$R \leq R', R = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (r'_{ijk} + r''_{ijk}) x_{ijk},$$

where  $T'$  is the permissible time allocated for the production and logistics of the supply of weapons to the zone of military conflict;

$W'$  is the permissible expenses related to the production and logistics of arms supplies to the zone of military conflict;

$R'$  is the permissible risks associated with the production and logistics of the supply of weapons to the zone of military conflict.

It is known that new types of weapons (for example, HIMARS), due to their tactical and technical characteristics (range, accuracy, etc.), can affect the effectiveness of the use of weapons in the zone of military conflict, by creating an asymmetry of military parity of forces (advantage of quality of weapons over quantity). Therefore, it is necessary to take into account the effectiveness of each type of weapon on the battlefield.

Assume that military specialists (experts) evaluate the effectiveness  $e_{ij}$  of each sample of the  $i$ -th kind and  $j$ -th type of weapons.

Subsequently, for all the weapons that will be sent to the zone of military conflict, the effectiveness will be presented in the following form:

$$E = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} e_{ij} x_{ijk}.$$

To successfully fulfill the goals of a combat operation in a zone of military conflict, it is necessary to calculate the following:

$$\max E, E = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} e_{ij} x_{ijk},$$

subject to restrictions:

$$T \leq T', T = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (t'_{ijk} + t''_{ijk}) x_{ijk},$$

$$W \leq W', W = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (w'_{ijk} + w''_{ijk}) x_{ijk},$$

$$R \leq R', R = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} (r'_{ijk} + r''_{ijk}) x_{ijk},$$

note that the estimates for  $e_{ij}$ ,  $t'_{ijk}$ ,  $t''_{ijk}$ ,  $w'_{ijk}$ ,  $w''_{ijk}$ ,  $r'_{ijk}$ ,  $r''_{ijk}$  military specialists must present all kinds and types of weapons in advance to solve the optimization problem set.

### 3. Development of a simulation model for studying the logistics supply chains of military equipment

To study the dynamic processes in the logistics of supply of weapons, ammunition and spare parts to the zone of military conflict, a simulation model was created, which allows, in the conditions of wartime risks, formation of supply routes, estimation of the time required for the transportation of military goods and the risks that arise due to threats of wartime. Supply routes are formed by military specialists in the field of logistics. If it is necessary to optimize the time or risks of supply, an algorithm has been created that allows minimization of the time of supply in a heterogeneous transport network, formation of a rational route taking into account the risks of wartime. The Any Logic system was used for modeling, with the help of which an agent simulation model was created. The simulation model agents include the following (Fig. 2):

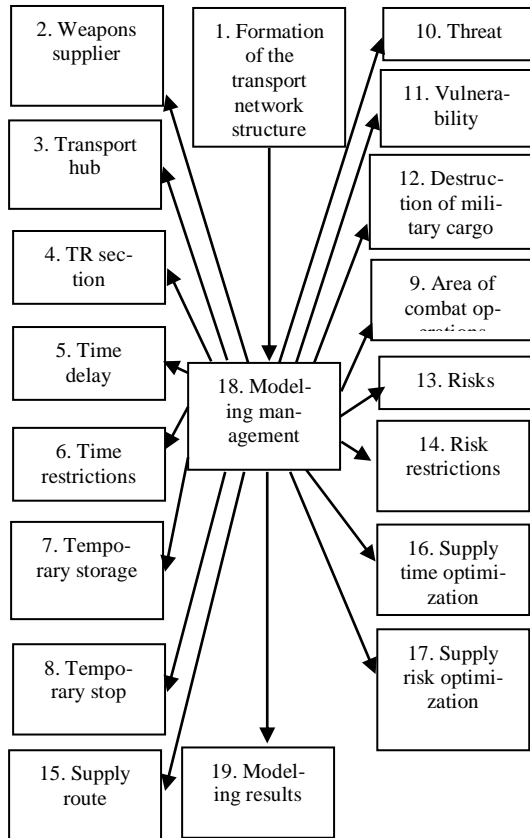


Fig. 2. Block diagram of the agent model

1. Agent "forming the structure of the transport network" (transport hubs and sections of the transport route);
2. Agent "supplier of weapons";
3. Agent "transport hub";
4. Agent "transport route section" (TR);
5. Agent "time delay";
6. Agent "time restrictions";
7. Agent "temporary storage";
8. Agent "time delay";
9. Agent "area of combat operations" (ACO);
10. Agent "threat";
11. Agent "vulnerability";
12. Agent "destruction of military cargo";
13. Agent "risks";
14. Agent "risk restrictions";
15. Agent "supply route";
16. Agent "optimization of supply time";
17. Agent "supply risk optimization";
18. Agent "modeling management";
19. Agent "modeling results".

Further, the modeling algorithm is described in brief.

First, the transport network is established using the "forming the transport network structure" agent. Further, to model the delivery path, the route using the "supply route" agent is set. With the help of the agent "supply of weapons", a batch of military cargo of weapons is formed in the application form in simulation modeling. Further, in accordance with the specified supply route, the sequence of applications is formed through all transport hubs (agent "transport hub") and sections of the transport network (agent "section of the transport route"), taking into account time delays (agent "time delay"), as well as temporary stops (agent "temporary stop") and the time required for temporary storage (agent "temporary storage"). When transporting military cargo, logistics risks accumulate with the help of the "risks" agent. To study the impact of threats on the logistics of military cargo supplies, the "threat" agent is used. The emergence of a threat leads to the excitation of a critical vulnerability (agent "vulnerability"), which is associated with critical hubs and sections of the transport route, which leads to temporary stops of military cargo (agent "temporary stop"), as well as the possible destruction of military cargo (agent "destruction of military cargo"). To solve routing optimization problems in a heterogeneous transport network, the developed route optimization algorithms are used to perform the following tasks:

1. Search for the minimum route time, in conditions of wartime risks.
2. Search for the minimum risk value of the route, in conditions of limited supply time.

To find the minimum route time, taking into account risks, the developed optimization algorithm generates "waves" of application movement and their clones, which are formed in transport hubs of the supply network. When forming a minimal route in terms of supply risk, the supply risk is used as the main factor. Supply route optimization algorithms use the "supply time optimization" and "supply risk optimization" agents, taking into account the constraints that are set using the "time restrictions" agent and the "risk restrictions" agent.

The following research results are generated using the "modeling results" agent:

1. Time of movement of military cargo (batch of weapons) for a given supply route to the ACO.
2. Time of delay of military cargo due to the supply period to the ACO.
3. Accumulated logistics risks of military cargo supply.
4. Time-optimum supply route of military cargo.
5. Risk-optimum supply route of military cargo.
6. Term of supply of military cargo to the ACO, in the event of a threat.
7. Military cargo delayed due to threats.
8. Military cargo destroyed due to threats.

#### 4. Formation of a set of military competencies required to use new systems weapons

For the successful implementation of the objectives of a military operation in the area of combat operations, it is necessary to form a set of weapons, which, in terms of their effectiveness, in general, exceeds the effectiveness of the enemy's weapons, due to the use of modern combat systems (for example, HIMARS MLRS). This can lead to asymmetry and superiority of forces in military parity in a zone of military conflict (advantage of quality over quantity). The use of new high-tech weapons systems requires the acquisition of new competencies in the military. The structural representation of the competencies associated with the use of a new type of weapon is shown in Fig. 3. Here, the core competencies are related to known types of military equipment and are part of the set of competencies that the military has.

Special new competencies arise when using modern weapons. The acquisition of new competencies requires training of military personnel in training centers,

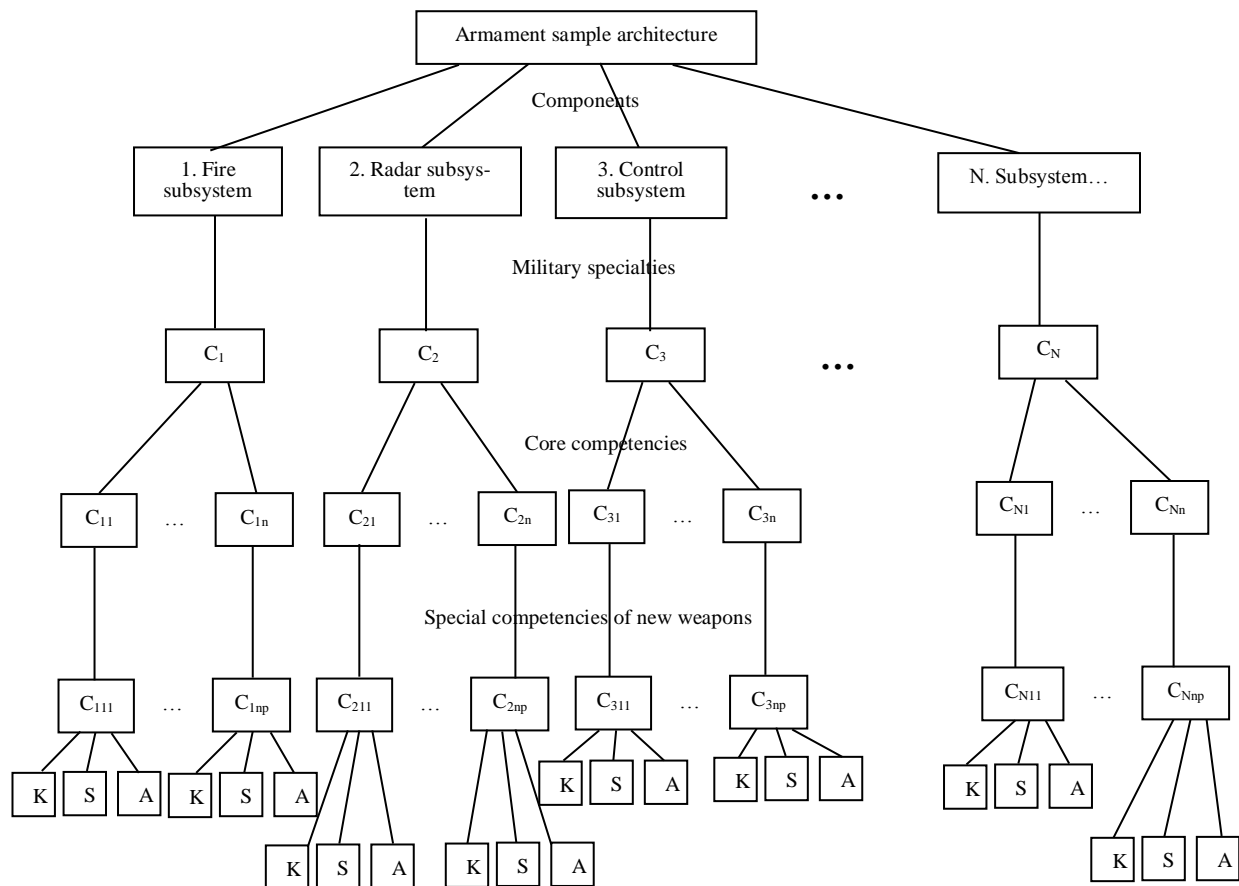


Fig. 3. Structure of competencies for the military to master new weapons

for acquiring new knowledge (K), formation of new skills (S) and consolidation of abilities (A). Training centers are located at a distance from the area of combat operations, which requires the transportation of military personnel, in conditions of military threats. Training centers need to provide new knowledge in a short time, using modern training methods (automated training systems, using simulators, conducting practical classes at special training grounds, etc.). Given the martial law and the active conduct of combat operations in the conflict zone, in order to train the military on new weapons systems, it is necessary to reduce the training time, as well as minimize the risks of martial law.

Assume that the difference  $\Delta_{ijk}$  in the knowledge of the military and the competencies required when using modern weapons is determined. This difference must be eliminated during the training of the military. It is necessary to choose the possible composition of competencies to be used for effective training.  $\Delta_{ijk}$  will be measured for the  $i$ -th kind of  $j$ -th type of possible  $k$ -th composition of competencies using military expert assessments. For example,  $\Delta_{ijk} = 0$  means that there is no difference between competencies,  $\Delta_{ijk} = 10$  corresponds to a complete discrepancy of competencies (new competencies that the military did not have before). Military experts believe that after conducting military training, a difference in competencies will be obtained  $\Delta'_{ijk} \leq \Delta_{ijk}$ ,  $\Delta'_{ijk} \rightarrow 0$ , for all  $i, j, k$ . Integer (boolean) variable  $x_{ijk}$  is introduced, the value whereof is  $x_{ijk}=1$ , that for the  $k$ -th composition of competencies, it is necessary to conduct training to master a new type of weapon of the  $i$ -th kind of  $j$ -th type. And for  $x_{ijk}=0$ , no training required, because that composition will not be used.

As a target optimization function, the total number of  $Q$  points will be used, which should be minimized when choosing the possible composition of competencies for the military to learn new types of weapons. Taking into account all kinds and types of weapons to be used in the zone of military conflict, the following is obtained:

$$Q = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} \Delta'_{ijk} x_{ijk},$$

where  $s_j$  is the number of possible variants of the composition of competencies, from which it is necessary to choose one for training new weapons of the  $j$ -th type of  $i$ -th kind;

$m_i$  is the number of types of  $i$ -th kind of weapons;

$M$  is the number of kinds of weapons used in the zone of military conflict. At the same time  $\sum_{k=1}^{s_j} x_{ijk} = 1$ , which means the mandatory selection of one  $k$ -th variant of the composition of competencies for conducting training on mastering the  $i$ -th kind of  $j$ -th type of weapons.

When carrying out the process of training the military, it is necessary to minimize the total difference in competencies:

$$\min Q, Q = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} \Delta'_{ijk} x_{ijk}.$$

When optimizing  $Q$ , it is necessary to take into account the restrictions, first of all, in terms of time –  $T$ , then in terms of wartime risks –  $R$ , and finally in terms of the costs of training centers during training –  $W$ :

$$T \leq T', T = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} t_{ijk} x_{ijk},$$

$$R \leq R', R = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} r_{ijk} x_{ijk},$$

$$W \leq W', W = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} w_{ijk} x_{ijk},$$

where  $t_{ijk}$  is the time to prepare the  $k$ -th possible composition of competencies for mastering a new type of weapon of the  $i$ -th kind of  $j$ -th type;

$r_{ijk}$  is the risk of preparing for the assimilation of the  $k$ -th composition of competencies, regarding new weapons of the  $i$ -th kind of  $j$ -th type;

$w_{ijk}$  is the expenses for training the military and mastering the  $k$ -th composition of competencies for a new type of weapons of the  $i$ -th kind of the  $j$ -th type.

$T', R', W'$  is the permissible time, risks and costs for military training.

If, due martial law, it is necessary to conduct accelerated training of the military, then, in this case, it is necessary:

$$\min T, T = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} t_{ijk} x_{ijk},$$

subject to compliance with restrictions:



$$Q \leq Q', Q = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} \Delta'_{ijk} X_{ijk},$$

$$R \leq R', R = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} r_{ijk} X_{ijk},$$

$$W \leq W', W = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} w_{ijk} X_{ijk},$$

$$R \leq R', R = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} r_{ijk} X_{ijk},$$

$$W \leq W', W = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} w_{ijk} X_{ijk}.$$

where  $Q'$  is acceptable difference in the competencies required for the use of new weapons systems and the competencies that the military will receive through training in training centers.

The logistical problem of delivering military personnel to training centers in the face of wartime threats is solved by using the developed method of agent simulation modeling (see point 3).

When using and mastering new weapons by the military, the attention shall be paid, first of all, to the effectiveness of kinds and types of weapons, which will allow, in the future, increase of the effectiveness of weapons, in general, in the zone of military conflict. Then, in the formulation of the optimization problem of military training, it is necessary to take into account the efficiency  $e_{ij}$  of each sample of the  $i$ -th kind of  $j$ -th type of weapons. At the same time, it is necessary to normalize the efficiency value  $e_{ij}$ :

$$e'_{ij} = \frac{e_{ij}}{\sum_{i=1}^M \sum_{j=1}^{m_i} e_{ij}}, \sum_{i=1}^M \sum_{j=1}^{m_i} e'_{ij} = 1.$$

$e'_{ij}$  will be used as a value indicating the need for military training, first of all, on the use of the most effective modern weapons in general.

Therefore, taking into account the effectiveness of weapons in the training of the military, it is necessary to calculate the following:

$$\min Q = \sum_{i=1}^M \sum_{j=1}^{m_i} e'_{ij} \left( \sum_{k=1}^{s_j} \Delta'_{ijk} X_{ijk} \right),$$

subject to the following restrictions:

$$T \leq T', T = \sum_{i=1}^M \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} t_{ijk} X_{ijk},$$

## 5. Example of choosing the composition of competencies to use a new combat system

Consider an illustrated example of training the military to use, in combat conditions, a new multiple launch rocket system (HIMARS type).

Modern MLRS includes three main subsystems:

- control;
- radar;
- fire.

For each of the subsystems, it is necessary to train military personnel, relevant specialties, for mastering new competencies, for the use of modern MLRS. For the convenience and simplicity of comparing possible variants of the composition of competencies, for training the military, qualitative assessments are used in the form of values of linguistic variables: training time –  $x_1$ , risks associated with logistics of military training –  $x_2$ , and costs necessary for the operation of the military training center –  $x_3$ :

$$x_1 = \begin{cases} A - \text{minimum training time;} \\ B - \text{satisfactory training time;} \\ C - \text{permissible training time;} \\ D - \text{maximum training time.} \end{cases}$$

$$x_2 = \begin{cases} A - \text{minimum training risk;} \\ B - \text{satisfactory training risk;} \\ C - \text{permissible training risk;} \\ D - \text{maximum training risk.} \end{cases}$$

$$x_3 = \begin{cases} A - \text{minimum costs;} \\ B - \text{satisfactory costs;} \\ C - \text{permissible costs;} \\ D - \text{maximum costs.} \end{cases}$$

The difference in competencies will be estimated as a percentage.

Three main types of competencies that the military needs to master in order to use the new MLRS are distinguished in the form of knowledge, skills and abilities:

1. Core principles of operation of the subsystem (knowledge).

2. Detailed representation of the functioning of the subsystem (skills).
3. Instructions for use and operating conditions of the subsystem (abilities).

Table 1 presents assessments of military specialists (experts) regarding possible variants of competence compositions for studying the main military MLRS subsystems.

Table 1  
Assessment of variants of the composition of competencies for military training

Subsystems	Variants	Competencies			Difference in competencies (%)	Training time	Training risks	Training costs
		1	2	3				
1. Control	1	-	-	+	35	A	A	A
	2	-	+	-	-			
	3	-	+	+	20	C	B	D
	4	+	-	-	-			
	5	+	-	+	25	B	B	C
	6	+	+	-	-			
	7	+	+	+	10	D	D	C
2. Radar	1	-	-	+	30	A	A	A
	2	-	+	-	-			
	3	-	+	+	20	D	C	B
	4	+	-	-	-			
	5	+	-	+	25	B	B	B
	6	+	+	-	-			
	7	+	+	+	10	D	D	C
3. Fire	1	-	-	+	25	A	A	A
	2	-	+	-	-			
	3	-	+	+	10	D	C	B
	4	+	-	-	-			
	5	+	-	+	15	B	B	B
	6	+	+	-	-			
	7	+	+	+	5	D	D	D

Analysis of the results of experts' assessment of possible versions of the composition of competences will be conducted for the justification and selection of the best version of the composition necessary for the training of the military.

Experts, when analyzing the variants of the composition of competencies for the three main subsystems of MLRS, excluded variants 2, 4, 6 from consideration for all subsystems, taking into account the absence of a third competence in the composition of competencies related to the skills of using the subsystem in combat conditions.

Further, due to low and unacceptable D scores, according to experts, which are present in some variants of

the composition of competencies, the following variants of the composition of competencies were excluded from further consideration:

In the control subsystem:

Variants 2, 4, 6, due to unacceptable cost values (D);

Variants 2, 4, 6, due to unacceptable time values (D) and risks (D).

In the radar subsystem:

Variants 2, 4, 6, due to the long training time (D);

Variants 2, 4, 6, due to unacceptable time values (D) and training risks (D).

In the fire subsystem:

Variants 2, 4, 6, due to unacceptable values of training time (D);

Variants 2, 4, 6, due to unacceptable values of time (D), risks (D), and training costs (D).

Further, the experts drew attention to a large unsatisfactory difference in competencies:

Variants 1 of the composition of competencies in the control subsystem (35%)

Variants 1 of the composition of competencies in the radar subsystem (30%)

These variants were also excluded from further consideration. As a result, the following options remain for the possible composition of competencies for the military to study the main subsystems of the new MLRS:

5, 5, 1

5, 5, 5

These variants have the following scores (see Table 1):

5, 5, 1:

25 %, B, B, C;

25 %, B, B, B;

25 %, A, A, A.

5, 5, 5:

25 %, B, B, C;

25 %, B, B, B;

15 %, B, B, B.

Finally, variant 5, 5, 5 was chosen to train the military for the use of MLRS.

## 6. Discussion

As a result of the research, new results were obtained, which, unlike the existing ones:

- take into account the diversity of kinds and types of military equipment entering the zone of military conflict;

- the heterogeneity and long length of logistics chains in the transport system for the delivery of goods to the zone of military conflict are taken into account;

- the remoteness of the repair base from the zone of military conflict is taken into account, which is represented as a reverse logistics chain for the delivery of military equipment for repair;

- the problem of accelerated training of military personnel under conditions military threats was researched and resolved.

### Conclusions

The conducted research is related to modeling the logistics process of supplying and mastering new types of weapons by the military, for the successful implementation of goals of a military operation in the area of combat operations. As a result of the preliminary analysis, the problems of using a variety of weapons. A systematic representation of the logistics of the supply of weapons to the military conflict zone was created, which is subsequently used to solve the main tasks of the research. The task of the optimal selection of suppliers of weapons, spare parts and ammunition for conducting combat operations in the zone of military conflict is set and solved, taking into account the efficiency of using weapons, time, costs and logistics risks. This takes into account the use of several possible manufacturers of military equipment for one kind and type of weapon. The agent simulation model has been created in the Any Logic environment, which takes into account the main components of the logistics supply process: the transport supply network, time delays, and supply routes. Optimization of the selection of supply route was carried out, in the face of threats and the occurrence of critical vulnerabilities, when supplying in a heterogeneous transport network. Using the simulation agent model, a rational route for the supply of weapons and military equipment is formed, the time and cost of supply are estimated, and the impact of threats on the supply time is taken into account. For the effective use of new weapons and military equipment, the process of training the military is studied using a set of competencies to be learned in training centers for reduced time, in conditions of threats of martial law and logistical risks. An example of training the military to use modern MLRS weapons is provided.

Mathematical methods and modeling methods are used: system analysis, expert evaluation methods, integer optimization, simulation modeling, multi-criteria decision-making methods, agent modeling.

The proposed approach allows planning the supply of new diverse weapons to the zone of military conflict and to select a rational composition of manufacturers of military equipment.

**Contribution of the authors:** a systematic representation of the logistical problem of supplying military

goods – **Oleg Fedorovich**; justification of the supply of weapons and military equipment – **Igor Chepkov**; formation of military competencies for the use of modern weapons – **Mikhail Lukhanin**; optimization of logistics supply chains of military goods – **Yurii Pronchakov**; development of an agent simulation model of supply with an example – **Kseniia Rybka, Yuliia Leshchenko**.

All authors have read and approved the published version of the manuscript.

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Надійшла до редакції 10.07.2022, розглянута на редколегії 25.08.2022

## МОДЕЛЮВАННЯ ЛОГІСТИКИ ПОСТАЧАННЯ ТА ПІДГОТОВКИ ВІЙСЬКОВОГО ПЕРСОНАЛУ ДО УСПІШНОГО ВИКОРИСТАННЯ ОЗБРОЄННЯ В ЗОНІ БОЙОВИХ ДІЙ

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Формується та вирішується задача багатоваріантного характеру, яка пов'язана з моделюванням логістичних дій, пов'язаних з різноманітною військовою технікою та озброєнням, яке надходить у зону воєнного конфлікту. Актуальність дослідження, пов'язана з комплексним рішенням проблеми логістичного характеру постачання та засвоєння військовими сучасної різноманітної зброї для створення паритету сил у зоні воєнного конфлікту. Метою дослідження є створення комплексу логістичних методів та моделей, які дозволяють проаналізувати підготовку військових, постачання озброєння, боєприпасів та запчастин в зону воєнного конфлікту, для успішного виконання цілей військової операції. В статті аналізується проблема використання сучасної різноманітної військової техніки, яка потребує рішення шляхом системного представлення в логістиці підготовки військових, постачанні різноманітного озброєння, від різних виробників, в зону бойових дій. Створена оптимізаційна модель для вибору та обґрунтування складу постачальників озброєння, запчас-

тин та боєприпасів, в умовах ризиків, які виникають у виробництві та транспортуванні військових вантажів в різномірній транспортній мережі. Оптимізація проводиться в умовах протиріччя критеріїв: кількість нового озброєння; час та витрати на виробництво та постачання військової техніки; ризики логістичного характеру. Для дослідження динамічних процесів у логістиці постачання озброєння, запчастин та боєприпасів, створено модель, яка дозволяє, за допомогою агентів імітаційного моделювання, дослідити шляхи руху військових вантажів в умовах воєнних загроз та можливих збуджень критичних вразливостей в різномірній транспортній мережі постачання. Розроблено алгоритм формування оптимального маршруту постачання за мінімальним часом в умовах ризиків. За допомогою імітаційного моделювання оцінюється час руху військових вантажів, запізнення в постачанні, накопичення ризиків в транспортуванні вантажів, наслідки виникнення загроз та вразливостей логістики постачання, тощо. Досліджується процес підготовки військових шляхом засвоєння нових компетентностей для використання сучасною різноманітною зброєю в бойових умовах. При цьому, враховуються стислі строки підготовки військових та логістика їх транспортування до центрів підготовки, з урахуванням загроз та ризиків воєнного часу. Ефективність запропонованого підходу забезпечується системним представленням логістики постачання різноманітної зброї, запчастин та боєприпасів у зону конфлікту, комплексним рішенням поставлених завдань дослідження. Наукова новизна дослідження, яке проводиться, пов'язана з розробкою нових методів та моделей, заснованих на системному аналізі. Були використані такі методи: імітаційного моделювання, моделі оптимізації, модель для засвоєння нових знань військовими, яка заснована на компетентностях, що забезпечує успішність виконання цілей військової операції. Результати дослідження доцільно використовувати для вибору та обґрунтування постачальників нового різноманітного озброєння та військової техніки, проведення підготовки військових для використання сучасних видів та типів озброєння, планування маршрутів та план-графіків постачання військових вантажів в зону бойових дій, в умовах загроз воєнного часу.

**Ключові слова:** зона бойових дій; логістика постачання; загрози та критичні вразливості; різноманітна військова техніка; постачальники озброєння; військові компетентності; агентне імітаційне моделювання; оптимізація.

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