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A variant of building an optimal plan for the target's distribution to forces and means of mechanized (tank) troops in an operation's simulation model (combat operations)

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Abstract. The relevance of the problem under study is confirmed by numerous analyses of the experience of modern military conflicts in general and the Russian-Ukrainian war in particular, which state that the most significant role in the operations of task forces remains assigned to units of mechanized (tank) troops, and therefore to their forces and means. This demonstrates the urgency of conducting comprehensive studies of the regularities of the processes that take place during the use of forces and means of mechanized (tank) troops. An important condition for achieving the objectives of an operation (general battle) is the optimal (best possible) distribution of forces and means to perform tasks to destroy the enemy. In this regard, this article is aimed at building an optimal plan for the target distribution to forces and means of mechanized (tank) troops in an operations simulation model. The leading method of operations research used to solve optimization problems is the linear programming method. This method allows a comprehensive consideration of the peculiarities of building an optimal plan for the target distribution to forces and means of mechanized (tank) troops. The article analyses the factors influencing the distribution of forces and means of mechanized (tank) troops, ranks typical targets for fire destruction by forces and means of mechanized (tank) troops by the indicator of importance (danger), develops a variant of building an optimal plan for the target's distribution for mechanized (tank) troops, and on its basis formulates a generalized algorithm for simulation the decision-making process and assignment of fire tasks in a simulation model of an operation (combat) of troops (forces). The materials of the article have theoretical value for further research on the problem, as well as practical value for improving the methods that are directly used in military headquarters when planning joint fire against the enemy.

Keywords: research of operations, mathematical simulation, distribution of forces and means, optimal plan, fire control of mechanized (tank) troops.

Introduction

High maneuverability and rapidity, richness and variety of weapons, and specificity of their use characterize modern combined arms combat. At the same time, the specificity of deployment is determined by the characteristics of weapons and the current tactical situation.

The main weapon systems of mechanized (tank) units are infantry fighting vehicles (IFVs), armored personnel carriers (APCs), and tanks, which in turn have different types of weapons (e.g., BMP-3 is equipped with a 100 mm smoothbore gun, 30 mm automatic gun, anti-tank missile system (ATMS) and machine guns). Different types of these weapons are designed to destroy different types of enemy targets that will be in the area of operations of mechanized (tank) units.

The diversity of both weapons and targets, along with changes in the tactical situation, require an optimal distribution of existing weapon systems (means) to effectively destroy the most important and dangerous enemy targets. The solution to this problem requires taking into account the importance and threat of the objects to friendly forces, as well as their characteristics that are important for choosing a certain type of weapon to defeat them with maximum efficiency.

In addition, in the course of the Russian-Ukrainian war, units of mechanized (tank) forces received from the allies weapon systems and military equipment of various production and tactical and technical characteristics (for example Javelin, NLAW, etc. ATGMs; IFV Bradley; Leopard tanks of various modifications). The study of the issue of targeting these fire systems that are not inherent in the domestic defence industry is necessary for the adequacy of the results of simulation of the operation (combat) as a whole, which determines the relevance and urgency of researching on the chosen topic.

Predicting the course and results of the actions of mechanized (tank) units and assessing the impact of the latter on the overall combined arms battle is a rather complex task. To solve it, simulation is usually used as a sufficient and affordable method of conducting the necessary research. At the same time, the accuracy of the results obtained largely depends on the completeness and correctness of taking into account the main factors (features) of all stages of a general combat.

Mathematical simulation of the process of fire control of forces and means of mechanized (tank) troops and their targeting is key in the simulation model of an operation (combat) (Romanchenko, 2017). This process is conducted to maximize their firepower in the context of the rapidity of a combined arms battle. It can be represented by constructing a specific targeting plan that must meet the requirement of optimality (be the best possible). The most appropriate method for solving problems of allocating certain forces and means (resources) is the method of linear programming, which is sufficiently covered, for example, in the literature on operations research (Wentzel, 1972), (Abchuk, 1979).

This and similar methods are aimed at building an optimal plan that meets the conditions of the task and meets the goal and can be used as a basis. At the same time, such methods do not fully take into account certain features of a general battle, namely the relatively low level of automation of the fire control process (Yudin, 1961). Under such conditions, the influence of subjective factors (in particular, the level of training of the respective commanders, tank, and IFV crews, their ability to correctly assess the level of threat of the target, etc.) imposes several restrictions that must be taken into account in simulation models. Otherwise, the simulation results will reflect only the results of solving an optimization problem, which does not always correctly reproduce the real processes of fire control in combat.

Materials and Methods

In general terms, the task of fire C2, decision-making, and assignment of fire missions for mechanized (tank) units, and as a result, the building of an optimal plan for the target's distribution to forces and means of mechanized (tank) troops can be formulated as follows (Milgram, 1968).

Suppose that there are m groups of different types of means (mechanized (tank) units) of their troops, each consisting of N units of weapons and must carry out fire damage to n detected objects of enemy military equipment. The objects of destruction (targets) are characterized by the coefficients of importance and danger p_j and vulnerability of the *j-th* object using the *i-th* group - w_{ij}.

Mathematically, the set of importance and hazard indicators can be described by a matrix of $n \in N$ classes of elements of the "vector" of means by $m \in N$ classes of elements of the "vector" of goals:

$$\|P\| = [p_{ij}], \tag{1}$$

where p_{ij} - is the value of the indicator of importance and danger j-class of objects of military equipment (weapons) of the enemy for $i$the -th class of means of the mechanized (tank) forces of the grouping of their troops, $i = 1, \dots, n, j = 1, \dots, m$.

Accordingly, a set of indicators of vulnerability of enemy military equipment:

$$\|W\| = [w_{ij}], \tag{2}$$

where w_{ij} - is the value of the vulnerability indicator j-class of enemy military equipment (weapons) for $i$the -th class of the mechanized (tank) forces of the grouping of their troops, $i = 1, \dots, n$, $j = 1, \dots, m$.

The allocation of assets to targets is characterized by the matrix $A = \|x_{ij}\|$, where x_{ij} is the number of assets of *the i-th* group assigned to the *j-th target*.

It is necessary to allocate means to targets in such a way that the mathematical expectation of the number of targets hit M_{max} taking into account their importance and danger is maximized (Danzig, 1966):

$$M_{max} = \sum_{j=1}^{n} p_j \left[1 - \prod_{i=1}^{m} (1 - w_{ij})^{x_{ij}}\right], \tag{3}$$

where. n - is the number of detected fire damaged objects (enemy vehicles);
m - the number of groups of destruction means (units of their troops);
p_j - is the importance and danger coefficient of the *j-th* object;
w_{ij} - vulnerability of the *j-th* object by means of the *i-th* group;
x_{ij} - is the number of means of *the i-th* group assigned to the *j-th* object of fire destruction

under the following conditions:

$$\begin{cases} \sum_{j=1}^{n} x_{ij} = N_i, i = 1,2 \dots, m; \\ x_{ij} \geq 0, i = 1,2, \dots, m, j = 1,2, \dots, n. \end{cases} \tag{4}$$

Results and Discussions

In general, the issue of studying the optimization of the distribution of various forces and means, as well as military resources, has been open for quite some time. For example, I. Kulinich (2020) proposed an approach to optimizing the allocation of air defense forces and means, and O. Poluiko (2016) put forward his version of the optimal allocation of air forces brigade's forces and means to specified targets in a massive strike for consideration by the academic community. In addition: V. Chuiev (2016) proposed models for calculating the results of combat operations of several task forces; B. Butvin (2019) published his vision of using modified equations of dynamics of averages for operational forecasting of the course and results of combat operations;

V. Nazarenko (2014) formulated a methodology for assessing methods of combat; O. Semenenko (2023) developed a mathematical model for solving a multi-criteria problem of choosing rational forms and methods of deployment of forces; O. Poluiko (2016) proposed an approach to the optimal allocation of forces and means of an air forces brigade; O. Drol (2020) put forward a methodology for determining the optimal number and type of weapon systems of mobile tactical task forces to effectively deter the enemy; S. Teliukov (2023) proposed an author's methodology for optimizing the composition of forces and means of the force protection observation post. Quite informative and useful are the works of V. Shvaliuchynskyi (2013) on optimizing the allocation of flight resources and B. Demianchuk (2023) on optimizing the volume of additional material reserves and combat equipment of transport logistics units. O. Zahorka (2023), O. Morozov (2015), B. Popkov (2013), and many others, also addressed other equally important tasks of optimizing processes in the military sphere. However, insufficient attention has been paid to the study of the problems of building optimal plans for the target's distribution to forces and means of mechanized (tank) troops in simulation models of operations (combat), and with the level of detail to a single unit of military equipment (weapons).

The above formulation of the problem of fire C2, decision-making, and assignment of fire missions to mechanized (tank) units can be solved by constructing an optimal plan for the distribution of firepower to the objects described above. Thus, we consider this problem as a transport problem of linear programming.

A universal method for solving linear programming problems is the simplex method, which is based on multiple recalculations of the system of constraint equations of the main linear programming problem concerning new free and base variables. However, the solution of such linear programming problems as transport problems can be obtained by simpler methods (Lysenko, 2017).

Since the number of detected objects (enemy military equipment) whose fire damage must be assigned to vehicles (units of your troops) is unknown in advance, we get a special case of the transport problem, namely the problem of assignment with an incorrect balance.

The solution to the problem of target distribution is based on the so-called Hungarian method (algorithm) of linear programming, the final result of which is an optimal plan matrix, in the subject area of the task of controlling the fire of mechanized (tank) units allows to fully achieve the condition of maximum mathematical expectation of the number of targets hit and to distribute firearms to targets, taking into account their importance and danger.

The number of steps $k$required to solve problem (3) by the Hungarian linear programming method is equal to the total amount of funds to be distributed:

$$k = \sum_{i=1}^{m} N_{i.} \tag{5}$$

The procedure for calculating the importance (threat) and vulnerability coefficients of targets should be noted separately. The concepts of "important" and "dangerous" targets are somewhat different, for example, the command post of an enemy battalion is an important target, and the position of a mortar battery that is firing on the positions of a mechanized (tank) unit is a dangerous target. Therefore, the task is to prioritize the targets to be destroyed. Indirectly, the priority of defeating the detected objects is determined in the work of O. Wentzel (1972), so, in our opinion, it is quite possible to build a priority series of the importance of targets using a single coefficient p_j. In other words, in any case, first of all, mechanized (tank) units will open fire at the most dangerous targets (anti-tank missile systems, tanks, IFVs, and APCs), then at the positions of command posts and command and control vehicles, and only then at the positions of enemy artillery, anti-aircraft missile units, etc.

The probability of defeating the *j-th* object by a weapon of *the i-th* group can be considered as the product of the dependent variables (Alekseev, 1989):

$$q_{ij} = v_i w_{ij}, \quad (6)$$

where v_i - is a coefficient that takes into account the level of training of the unit's personnel;
w_{ij} - vulnerability of the *j-th* object using the *i-th* group.

The coefficient v_i takes into account the level of training of personnel in the use of the *i-th munition*. Since the level of training of personnel is generally a random variable, several assumptions can be made.

The time factor in the context of the rapidity of combat is quite important and must be unconditionally taken into account in the simulation model. In addition, the level of training of personnel can be determined by the time standards for performing certain exercises using the *i-th munition, i.e., the* coefficient v_i is a function of time. Assuming a normal law of distribution of the time spent by personnel to perform a certain exercise using the *i-th munition*, its distribution function $F_i(t)$ on the interval $t_1 \div t_2$ will have the form shown in Fig. 1. The boundary values of this interval correspond to the standard values for performing control exercises using different munitions against typical targets (e.g, t_1 - corresponds to the normative time for an "excellent" score, t_2 - "satisfactory").

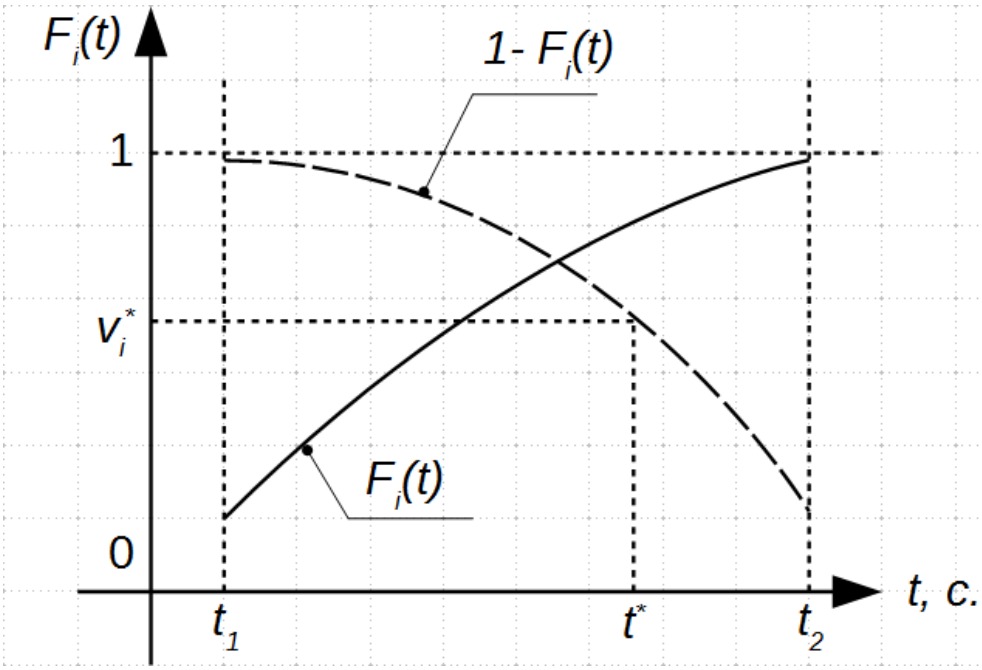


Figure 1. Distribution function $F_i(t)$

Since the level of training of personnel is usually unknown in advance, a certain value of the coefficient v_i is selected using a random variable t uniformly distributed over the interval $t_1 \div t_2$and the function $\left(1 - F\middle|\ \middle|i(t)\right)$ (Fig. 1). This approach will to some extent allow to take into account the influence of the subjective factor in calculating the results of actions of mechanized (tank) units.

As a result of the research on this topic, an algorithm for simulating the actions of units (parts) of mechanized (tank) troops was developed, which is carried out step by step and whose core is the proposed option for building an optimal plan for the targeting of forces and means of this type of troops (Fig. 2).

Building an optimal plan for the target distribution to forces and means of mechanized (tank) troops is a key procedure (structural element) of the proposed algorithm. The optimal targeting plan is built at each simulation step of the operation (combat operations), taking into account the importance and danger of the targets for fire damage available at a particular simulation step.

The proposed variant of building an optimal targeting plan is complex and, unlike the approaches proposed by O. Sobolev (2010) and V. Stebletskyi (2010), takes into account the level of training of personnel.

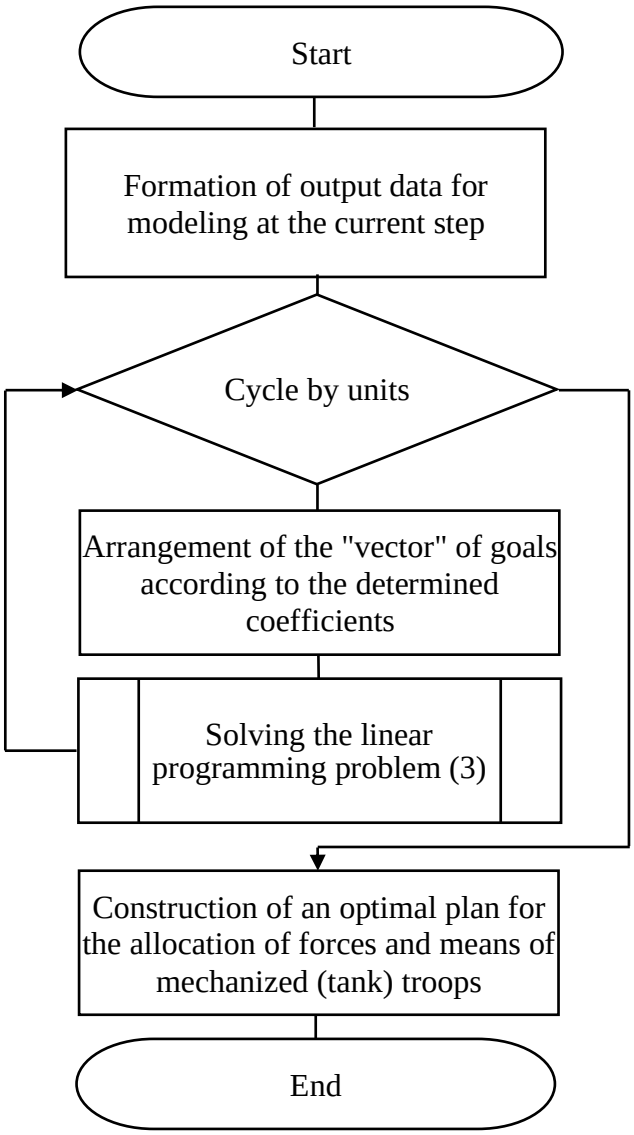


Figure 2. Flowchart of the algorithm for decision-making and assignment of fire tasks to mechanized (tank) units

Direct targeting is carried out during the operation of the "optimization problem solving" block of the algorithm and is carried out for each element of the set of means. Thanks to the previous steps of the algorithm, it can be argued that the set of objectives and the set of means include the objectives identified as the most important and dangerous in the given situation and the means whose effectiveness in the relevant class of objectives is the highest.

Conclusion

The proposed author's variant of building an optimal plan for the target distribution to forces and means of mechanized (tank) troops in the simulation model allows for taking into account the peculiarities of the fire C2 process, decision-making, and tasking of mechanized (tank) units. In addition, its use will make it possible to take into account the influence of the subjective factor and the actions of the respective commanders under conditions of a sufficiently low degree of automation of such a process. By taking into account the influence of the coefficients of importance and danger of enemy targets during the fire C2 of the forces and means of mechanized (tank) troops on the course and results of the operation (combat operations), a preliminary assessment of the simulation results showed an increase in their accuracy and reliability in terms of key performance indicators. The main academic novelty is the method of assigning targets to mechanized (tank) units by solving a transport (optimization) problem using the Hungarian linear programming method. As a direction for further research, it is proposed to consider improving the mathematical model of actions of mechanized (tank) units by taking into account additional partial indicators, such as the terrain of the area of operation (combat), the role of the unit in the plan of the senior commander, the place in the combat order, mathematical simulation of intelligence at the tactical level, etc.

Recommendations

The materials presented in this article may be useful for specialists (researchers and teaching staff) in the field of mathematical simulation of complex military systems, as well as for higher education students (cadets, students, trainees, and associate students) studying these issues.

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