ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

UDC 62-503.57

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IMPROVEMENT OF THE MODEL AND METHOD OF ARTILLERY INSTALLATION TARGET DAMAGE CONTROL WITH MINIMAL COMBAT CAPABILITY LOSS

О. Максимова, В. Болтьонков, П. Гульцов, О. Максимов. **Удосконалення моделі і методу керування ураженням цілі артилерійською установкою при мінімальній втраті боєздатності.** Артилерійські установки збройних сил держави забезпечують її безпеку й суверенітет. Сучасні артилерійські установки виконують бойову роботу, близьку до завдань тактичних ракет, зі зменшеними часом та ресурсами. Складовою частиною військового мистецтва є тактика, якій притаманне інформаційне середовище та його проведення спеціалізованими підрозділами. Невід'ємною частиною тактичних досліджень будь-якої бойової операції є її математичне моделювання. Певний інтерес представляє можливість отримувати результати моделювання в разі принципової відсутності деяких видів бойових ресурсів, або використання тільки одного виду озброєнь. Розроблено модель керуванням бойовою роботою артилерійської установки яка розв'язує виконання бойового завдання по знищенню цілі заданою кількістю снарядів при умові зміни вогневої позиції для зменшення ймовірності її вогневого ураження артилерійською установкою протиборчої сторони. Модель враховує, що всі постріли ефективні. В модель введено припущення, що кількість вогневих позицій дорівнює кількості пострілів, а мінімальна кількість пострілів з вогневої позиції дорівнює одиниці. Модель зміни позиції не передбачає повернення на попередні. Моделювання переміщення з одної позиції на іншу відбуваються по одній з доріг різної якості. Розроблено метод пошуку рішення про стан виконання бойової задачі артилерійською установкою атакуючої сторони. Введено поняття поточної структури виконання бойового завдання. Метод пошуку рішення про стан виконання бойової задачі артилерійською установкою можна віднести до розв'язання Парето–орієнтованих задач, або задач динамічного програмування. Метод розрахунку моделі складається з загального алгоритму, в основу якого покладено спеціалізовані додаткові алгоритми. Отримані результати довели можливість виконання бойового завдання при одному максимум при двох пострілах з кожної вогневої позиції. Як що, тактика витрати пострілів по знищенню цілі в кількості 10 орієнтована на оборону тактику, то тактика по знищенню цілі в кількості 4 пострілів може відповідати бойовим діям при наступі. Тому тактику в перекладі з англійської «вистрілив і втік» для наступу можна назвати «сховався і вистрілив» «hid and shot».

Ключові слова Артилерійська установка, модель керування, поточна структура, метод пошуку рішення, задача динамічного програмування, алгоритм, автоматизована система керування

O. Maksymova, V. Boltyonkov, P. Gultsov, O. Maksymov. **Improvement of the model and method of artillery installation target damage control with minimal combat capability loss**. Artillery systems of the armed forces of the state ensure its security and sovereignty. Modern artillery systems perform combat work close to the tasks of tactical missiles, with reduced time and resources. An integral part of military art is tactics, which is inherent in the information environment and its implementation by specialized units. An integral part of tactical research of any military operation is its mathematical modeling. Of particular interest is the possibility of obtaining simulation results in the case of the fundamental absence of some types of combat resources, or the use of only one type of weapons. A model of controlling the combat work of an artillery i system has been developed, which resolves the execution of the combat task of destroying the target with a given number of shells under the condition of changing the firing position in order to reduce the probability of its fire damage by the artillery installation of the opposing side. The model considers that all shots are effective. The model assumes that the number of firing positions is equal to the number of shots, and the minimum number of shots from a firing position is equal to one. The model of change of position does not involve a return to the previous ones. Simulations of movement from one position to another take place along one of the roads of different quality. A method of finding a decision on the state of execution of the combat task by the artillery system of the attacking party has been developed. The concept of the current structure of combat mission performance is introduced. The method of finding a solution about the state of execution of a combat task by an artillery system can be attributed to the solution of Pareto-oriented problems, or dynamic programming problems. The model calculation method consists of a general algorithm, which is based on developed specialized additional algorithms. The obtained results proved the possibility of carrying out a combat mission with a maximum of two shots from each firing position. Just as the tactic of expending shots to destroy a target in the amount of 10 shots is focused on defensive tactics, the tactic of destroying a target in the amount of 4 shots can correspond to combat actions during the offensive. Therefore, the "shot-and-scoot" offensive tactic can be called "hid-and-shot".

Keywords artillery system, control model, current structure, solution search method, dynamic programming problem, algorithm, automated control system

1. Introduction

Artillery and tactical missile systems of a state's armed forces ensure its security and sovereignty. Modern artillery systems perform combat tasks similar to those of tactical missiles but with reduced

DOI: 10.15276/opu.2.68.2023.11

time and resources [1, 2]. An analysis of military actions in the Russian-Ukrainian war and recent global conflicts demonstrates the use of artillery units as the main tool for executing tactical plans, as 80% of the tasks related to inflicting enemy fire damage were assigned to artillery.

Contemporary military art, considering the speed of combat engagements between opposing sides and the intensive use of troops, and consequently, the various scales of combat operations, suggests using powerful fire systems with automated control systems to overcome first and second-degree information barriers [3].

A component of military art is tactics, which encompasses the theory and practice of preparing modern combat in an informational environment and conducting it with specialized units. Tactics are logically interconnected with strategy and the principles it follows. The practice of tactics includes the activities of commanders, staff, and troops (forces) in preparing and conducting combat. The theoretical part of tactics focuses on the regularities, nature, and content of combat and develops methods for its preparation and conduct. An integral part of tactical research of any combat operation is its mathematical modeling [4]. A particular interest is the possibility of obtaining modeling results in the absence of certain types of combat resources or using only one type of weaponry.

An analysis of global military conflicts, particularly in Iraq [5], Afghanistan [6], Syria, and the Russian-Ukrainian war [7], revealed that artillery fire determines the main power component of combat actions.

Tactical instructions for organizing and managing the combat operations of artillery units in the armed forces of any country's army emphasize the importance of moving artillery units during combat, and this is given considerable attention. The main emphasis in the manuals is on describing the selection of fire positions and movement routes.

Field regulations of the artillery units of the Armed Forces of Ukraine specify that the unit commander decides to change the fire position based on the time factor. The decision to move takes into account the time interval spent at the current fire position, the number of shots fired, and the degree of threat. It is important to note that the artillery unit commander needs to model all factors significantly affecting combat readiness and ability to complete the combat task beforehand.

This includes considering meteorological data, the state of the surrounding environment, logistical channels for ammunition and material supply, the enemy's reconnaissance capabilities and only then make, a decision on the route to move to a new fire position. Mathematical models need to incorporate as many factors as possible that affect efficiency and combat readiness.

In the following material, it is understood that an artillery unit consists of artillery units. The side that fires first is the attacking side, and the side targeted by the attacking side's fire is the opposing side. The attacking side's artillery units conduct fire actions against the opposing side's targets. The opposing side's artillery units conduct fire actions against the attacking side's artillery units.

Targets for the opposing side to hit include bridges, military logistics centers, radar systems, anti-aircraft assets, and equipped elements of the defensive system. The opposing side also has its artillery units, whose task is to detect and destroy the attacking side's artillery units with retaliatory fire. The opposing side's artillery units are located separately from the targets. The opposing side's artillery units fire at the attacking side's artillery units, but the attacking side's artillery units only fire at targets of the opposing side and do not fire at the opposing side's artillery.

There can be organizational control of artillery units, where the commander of the attacking unit orders to concentrate all fire on the opposing side's targets. However, for rational effectiveness, the commander of the attacking side may frequently change one fire position for another to avoid counter-fire.

From the provided material, it emerges that the attacking artillery unit has an advantage at the first salvo from a new firing position because the opposing side cannot return fire until the attacking side reveals its position with the first salvo. After the first salvo, both the attacking artillery unit and the opposing side are aware of each other's location and continue to exchange fire based on their corrective capabilities and the characteristics of their installations. The probability of hitting each other and the target may be low for both sides after each change of fire position. As long as the attacking side's artillery units remain at the current firing position, the accuracy of both sides improves from shot to shot, as both can adjust fire on their chosen targets. The commander of the attacking artillery unit makes corrections based on information received from observation means about the results of fire from the previous position and, if time permits, from the current position. The opposing side can also receive information about the coordinates of the attacking artillery units for adjusting their fire, and also based on reports from their counter-battery radar about the attacking side's fire on targets.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

It should be noted that the attacking side does not receive any additional information about the targets by observing the fire of the opposing side's artillery units, as their artillery units and targets are not located nearby. Eventually, in a prolonged engagement, the attacking artillery units move to a new location, and the process repeats. The attacking side's strength lies in its constant awareness of the location of the opposing side's targets from one firing position to another. However, after each position change, effectiveness decreases due to potential errors in determining the coordinates of the current firing position, environmental conditions, and reduced combat capability of the artillery installation during movement.

2. Analysis of literature sources

From the above, an analysis of the tactics of artillery units during maneuver warfare is warranted. The mobility of artillery is key to maintaining the given level of combat readiness of the unit, as the opposing side can determine the location of artillery units using counter-battery measures and respond with fire [8].

Literature models outline conditions for changing the firing position of artillery units. The advantages of firing artillery from a fixed position include increased accuracy, as adjustments are made during target engagement based on the results of previous shots.

However, the longer an artillery unit remains in position, the more likely it is that the opposing side will open counter-fire. This necessitates increasing the maneuverability of artillery units to avoid incoming fire, as the opposing side's ability to respond promptly increases.

This led to the emergence of the "shoot-and-scoot" tactic, where artillery units change firing positions immediately after firing at a target [9]. Literature review shows that the "shoot-and-scoot" tactic has been used in support forces as a means of creating unrest [10] and by main forces in defensive measures to minimize personnel and artillery unit losses.

Latest-generation artillery units are characterized by increased rapid-firing and mobility, capable of firing from one position, then moving to a new position and firing again within minutes [11]. These capabilities led to the development of a new tactic for offensive actions while using the defensive "shoot-and-scoot" approach. This new tactic, called "hide-and-seek", involves multiple cycles of firing and changing firing positions by the attacking side's artillery units [12].

Literature models consider the rapid-firing capability of artillery units and how their striking ability improves over time. In [13], models are proposed for volley schemes, aiming procedures, errors that occur during combat, and the probability of a shell hitting a target. Models determining methods of moving from one firing position to another are proposed, taking into account feedback from previous shots to increase firing accuracy [14, 15]. Methods and models have been developed to determine when each artillery installation should fire at specific targets [16, 17].

Works considering the movement of artillery units are highlighted [18, 19]. These propose methods for selecting firing positions and routes between them, considering the terrain's topology. A Markov model of artillery combat was suggested to assess the organization of combat work [20]. The model excludes efficiency loss, accelerated material wear, and time loss due to movement, but does not account for combat capability reduction due to hits by the opposing side while the artillery unit is on the move. A Markov model was proposed to analyze when an artillery unit should change firing positions to reduce combat capability due to counter-fire [21]. The model includes an algorithm where the attacking side starts targeting from an unknown position of the opposing side, which then identifies the firing position after several shots by the attacker. It's noted that model [21] is based on the attacking side trying to avoid counter-fire from the opposing side by changing positions using the "shoot-and-scoot" tactic. Authors [22] conclude that such tactics for preserving combat capability correspond to secondary fire tasks and summarize that main fire tasks may require the attacking artillery unit to expose itself to fire to continue combat.

Modeling in [21] examines the system's stationary properties, while in [22], a model is compiled for analysis under the condition of minimizing the time to destroy a target by the attacking side, which fires upon the opposing side. Additionally, [22] models the timing window, tracking current time and loss of combat capability of the attacking side's artillery unit.

Current combat operations show that counter-battery capabilities have significantly improved. Authors [22] make a reasoned assumption that the attacking side will be detected after the first shot, and the artillery unit may face a response from the opposing side. Analysis [22] focuses on how effective the opposing side's fire impact on the attacker should be and how valuable the target is for the attackers before they start reducing their artillery unit’s combat capability before moving on. Model [22] also considers a crucial factor absent in other models: the attacking side benefits from firing from the same place due to increased speed and accuracy of fire. Therefore, research that refines models for managing target damage by an artillery unit with the loss of combat readiness is relevant.

3. Objective and tasks of the article

The attacking side has initial information about the coordinates of the opposing side’s targets, prepares thoroughly for this, and opens fire first. After the first attacking shot, the opposing side will determine the approximate location of the firing artillery units and, as the number of shots increases, will identify the coordinates of these installations and open fire in response with sufficient accuracy. At some point, after a series of shots, the attacking side may move its artillery units to a new firing position to avoid back fire. Once relocated to the new firing position, the attacking artillery unit makes a salvo at the opposing side’s targets without losing combat capability, as the new firing position is unknown to the opposing side. This situation ends after the first salvo from the new position.

The article aims to improve the method and model for effectively managing the combat work of an artillery unit when hitting a target under the condition of changing the firing position to ensure minimal loss of combat capability and optimal timing.

To achieve this objective, it is necessary to:

– refine the simulation model for managing the combat work of an artillery installation when hitting a target, ensuring the calculation of the current state of combat capability;

– enhance the method of decision-making about the status of the combat task execution by the attacking side’s artillery installation under the condition of the opposing artillery installation executing fire on the current firing position of the artillery unit and its change to another.

4. Models and methods

The artillery battery model [21] facilitates the exploration of combat work conditions for various types of artillery weaponry, from mortars to heavy self-propelled installations, through the adjustment of configuration parameters. This model is represented as a non-reducible recurrent Markov chain in the implementation of certain states, allowing the artillery battery to be viewed as a single entity for comparing weapon systems and combat work algorithms. The state space equations can be solved in the form of boundary distributions, as the Markov chain is non-reducible and positively recurrent. The outcome of this search is the time interval that the artillery battery will spend in a state providing fire support [21].

The logical structure of the artillery battery’s combat work model is based on practical experience. Each time the battery occupies a new firing position, it remains unnoticed by the opposing side. The main source for detecting the battery is passive acoustic counter-battery radar. Radar detection of the first shot allows for determining the location of the battery with rational error and probability [23]. The probabilities of detecting a single and multiple volleys are the same. The likelihood of detection depends on the number of shots fired before detection. The sequence of targets of various types follows a homogeneous Poisson distribution. The artillery battery carries out a set number of shots at each type of target [21]. The artillery battery changes its firing position after completing a predetermined number of shots to obtain detection information. With information about detection, the artillery battery is highly likely to leave the firing position before the opposing side’s attack. While moving between firing positions, the artillery battery cannot perform fire tasks. During an attack by the opposing side on the firing position, the artillery battery suffers losses and combat damages, rendering it temporarily or permanently incapable of performing combat tasks.

Based on the above, the recurrent Markov chain for the artillery battery has various states that differently reduce its current combat capability in the event of arising situations [21, 23]:

– in the firing position providing fire support, has executed a certain number of volleys from the current position, but has not been detected by the opposing side;

– in the firing position providing fire support, has executed a certain number of volleys from the current position, detected by the opposing side, but does not have this information;

– in the firing position not providing fire support, detected by the opposing side, has this information and is preparing to leave the firing position;

– during movement to a new firing position not providing fire support;

– unable to provide fire support for some time due to ammunition exhaustion or permanently due to loss of combat capability.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

The initial data for modeling the execution of a combat task include: the number of targets, the speed of target detection, the number of shots to hit a target, the probability of battery detection during firing, the average time of combat work before the opposing side's attack on the battery after detection, the speed of battery recovery after an attack, the speed of battery movement between firing positions, the probability that the battery will be attacked during movement, the speed of the opposing side's detection of the battery's commencement of combat work, and the speed of leaving the firing position after deciding to change it [21].

The battery's combat capability is significantly influenced by the actions of surrounding systems of the opposing nature. The artillery installation's resistance to impacts from opposing systems can be conditionally termed "combat capability". This "combat capability" implies not only resistance to mechanical loads, vibrations, shocks, pressure, acceleration, load, electrical strength, moisture resistance, corrosion resistance, and radiation but also counteraction to destruction efforts by the opposing side. Practically, the general set of elements comprising an artillery installation is subjected to significant load, determining the number of elements that fail during a specified period of operation. This results in obtaining failure intensities of elements for a given load level.

Then, some parameters are changed one by one, and the entire experiment is repeated under new conditions. This yields information about the character of failure intensity changes of the analyzed elements and the scale of the load. Thus, failure intensity can replace the measure of combat capability [27].

The mathematical model of the combat capability of an artillery installation can be represented as follows. In military practice, the combat readiness of an artillery battery is commonly assessed by two probabilistic components [24, 25] the occurrence of sudden failures and failures due to wear.

Sudden failures are modeled by an exponential law, where combat capability is represented as failure-free operation and is defined as:

$$P(t) = e^{-\lambda t},$$

where λ − is the intensity of sudden failures affecting the initial velocity of the projectile when exiting the barrel, the speed of transporting the installation from one firing position to another, and the energetic characteristic of the artillery charge – the strength of the powder.

In general, the failure intensity can be expressed as:

$$\lambda = -\frac{1}{P(t)}\frac{dP(t)}{dt}.$$

Also, for any distribution law, the following is significant:

$$\lambda = \frac{f(t)}{P(t)}, \tag{1}$$

where $f(t) = -\dfrac{dP(t)}{dt}$ − is the frequency of failure probability.

Under normal combat operation for the exponential law, the failure intensity is a constant value. When combat capability is lost, the failure intensity starts to increase, and failures due to loss of combat capability, which in technical practice are modeled by the normal distribution law, are added to sudden failures:

$$P_u(t) = \frac{1}{\sigma\sqrt{2\pi}}\int_t^{\infty} e^{-(t-M)^2/2\sigma^2}dt,$$

where M − is the average value of combat capability.

The standard deviation from the average combat capability is defined as:

$$\sigma = \sqrt{\frac{\sum (t-M)^2}{N}},$$

where N − is the number of failures over time t.

The joint probability of combat capability of an artillery installation considering sudden failures and failures due to loss of combat capability over the period from $t_0 = 0$, to time t is determined by the expression:

$$P(t) = e^{-\lambda t} P_u(t).$$

If an artillery installation has partially lost combat capability, the joint possibility is determined as:

$$P(t) = e^{-\lambda t} \frac{P_u(t_0 + t)}{P_u(t_0)}. \quad (2)$$

Although expression (2) allows for the determination of the combat capability of an artillery installation at any point in time, it has several drawbacks within the scope of this study. For example, irregular operation of a technical system leads to its accelerated wear. According to field observations, the failure intensity significantly depends on the quality of operation of the artillery installation in accordance with its passport requirements. When the load exceeds the nominal level, there is a rapid increase in failure intensity. Furthermore, the proposed expression does not account for the abrupt decrease in combat capability in case the installation is hit by the opposing side. On the other hand, the failure intensity decreases when the load is lower than the nominal level [26].

Since the described factors primarily affect failure intensity, the following expression is used for modeling reliability:

$$P(t) = e^{-\int_T^{T+t} \lambda dt} = e^{-\lambda_b t + \int_T^{T+t} \lambda_u dt}. \quad (3)$$

where λ_b – is the intensity of sudden failures, and λ_u is the intensity of failures due to loss of combat capability.

To determine the intensity of failures due to loss of combat capability, the following approach can be used. From formula (1), in general, the failure intensity is determined as $\lambda = f(t) / P(t)$.

Consider the following scenario. During the simulation modeling, the combat capability of the installation can be increased by a certain value Δt on each iteration of the current working time, and then the current intensity of failures due to loss of combat capability is determined using formula (3). Suppose, during the current iteration of modeling, the artillery installation is subjected to forced impact, leading to an increased loss of its combat capability. Then, to model the increased loss of combat capability, it is sufficient to add the value Δt to the current time of the installation, corresponding to the amount of reduced system combat capability. The dependency $P(t) = e^{-\lambda t}$ corresponds to the theoretical model of changing combat capability over time for sudden failures. The dependency $P(t) = \frac{P_u(T+t)}{P_u(t)}$ describes the change in combat capability during combat operations, but without destruction by the opposing side [28].

5. Main part of the research

5.1. Simulation model for managing the combat work of an artillery installation

Let's develop a model for the task of managing the combat work of an artillery installation in the following setup. Artillery installation AU1 must complete a combat task, which involves destroying a stationary target with n shells while fully prepared for firing with the possibility of changing the firing position to reduce the likelihood of being hit by artillery installation AU2.

For solving the set task, we introduce assumptions for modeling. Assume that the number of firing positions equals the number of shots n required to hit the target. Moreover, the minimum number of shots from a firing position is one, meaning at least one shot must be executed from the current position. Changing positions does not imply returning to previous ones. Transition from one adjacent position to another occurs sequentially on one of s roads with varying surface quality and different probabilities of being hit by the opposing side. While executing the combat task by AU1, the possibility of movement and being hit by AU2 is considered impossible.

We define the initial state of combat capability of artillery installation AU1 K_{mch}. The mathematical model is formulated to determine the current combat capability of the artillery installation, considering its loss due to being hit by the opposing side's artillery installation and its movement from one position to another for further task execution of destroying the target.

To account for the dynamics of the AU1 and AU2 artillery installation systems, the following processes of actions (A, B, and C) are considered. For AU1, A – at the firing position: (A1 – transition from march to combat state; A2 – combat work of AU1 on the target; A3 – transition from combat

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

state at the firing position to march. B – Changing the position. For AU2, C – at the firing position: (C1 – combat work of AU2 on the stationary target AU1 after its first shot until the end of the transition from combat state at the firing position to march; C2 – combat work of AU2 on the moving target AU1 during the change of its firing position).

The events considered and occurring over time:

– event A1 is characterized by the time interval of AU1's transition from the march to the combat state at the firing position t_{mb};

– event A2 is characterized by the time interval of AU1's work on the target at the firing position for one shot t_{AU1}, in the case of several shots the total time increases;

– event A3 is characterized by the time interval of AU1's transition from combat state at the firing position to march state t_{bm};

– event B is characterized by the time interval of the march when changing the firing position to another t_m^j on j-th $(j=1...s)$ road;

– event C1 is characterized by the time interval of AU2's work on the target at the firing position for one shot t_{AU2} and the flight time of the projectile from the firing position to the stationary target t_{st};

– event C2 is characterized by the total time interval t_m^j on j-th $(j=1...s)$ road and the time interval of AU1's transition from march state at the firing position to combat state t_{bm}.

All events that reduce its state affect the current state of combat capability of the artillery installation AU1.

The impact of event A2 on changing the combat capability of AU1 is characterized by the amount of decrease in combat capability due to the wear of the barrel k_i^{stv} for one shot at the firing position and the amount of decrease in combat capability due to the wear of the AU1 running part k_i^{hod} for one shot.

The impact of event B on changing the combat capability of AU1 during transportation on j-th road $(j=1...s)$ is characterized by the amount of decrease in combat capability due to wear of the barrel $k_{stv\_tr}^j$ and the amount of decrease in combat capability due to wear of the running part $k_{hod\_tr}^j$.

The impact of event C1 on changing the combat capability of artillery installation AU1 is characterized by the amount of decrease in combat capability k_{vs} due to hits by shells from AU2 in AU1 depending on the number of shells *d*, fired from AU2 at AU1 to stop firing at the target:

$$k_{vs} = \sum_{j=1}^{d} \frac{1}{j(j+1)}.$$

The number of shells *d* is calculated by the expression under the condition that AU1 makes a_i shots at the target while performing combat work at position $(i=1...n)$:

$$d = \mathrm{INT}\left(\frac{a_i t_{\mathrm{AU1}} + t_{bm} - (t_{AU1} + t_{st})}{t_{\mathrm{AU2}} + t_{st}}\right),$$

where INT− is the extraction of the integer part of the obtained real number.

The impact of event C2 on changing the combat capability of artillery installation AU1 is characterized by the amount of decrease in combat capability $k_{m\_tr}^j$ due to wear of the installation during the enemy's fire impact when transported by j-th road $\left(j=1..s\right)$.

Thus, the value of combat capability of AU1 PA_i after combat work at position *i* $(i=1...n)$ is calculated by the formula:

$$\mathrm{PA}_i = \mathrm{PB}_{i-1} - (k_{vs} + k_{stv} t_{\mathrm{AU1}} a_i + k_{\mathrm{hod}} t_{\mathrm{AU1}} a_i),$$

where PB_{i-1} − is the combat capability of AU1 after changing position $i-1$ to position *i*, provided $\mathrm{PB}_0 = K_{mch}$.

The reduction of combat capability of AU1 when changing position *i* to position $i+1$ $(i=1...n-1)$ is calculated by the formula:

$$\mathrm{PB}_i = \mathrm{PA}_i - (k^j_{stv\_tr} + k^j_{hod\_tr} + k^j_{m\_tr}).$$

The combat capability of artillery installation AU1 after completing the combat task with n shots under the condition that the last n-th shot was executed at position k $(k \le n)$ equals PA_i.

5.2. Method for finding the solution to the combat task of the attacking side

To develop a computational method for finding the solution about the state of execution of the combat task by the artillery installation of the attacking side, under the condition of the opposing artillery installation executing fire on the current firing position of the artillery unit and its change to another, we proceed to define the input data.

We define an array $a[1\ldots n]$, where each element $a(i)$ equals the number of shots at the i-th current firing position. We also define an array $b[1\ldots n-1]$, where each element $b(j)$ corresponds to one of three roads for changing the j-th firing position to the next.

The current structure of task execution is defined as the sequence of the number of shots at each of the firing positions and the numbers of the roads used for changing positions: $a(1);\quad b(1);\quad a(2);\quad b(2);\ldots a(n).$

We set the initial value of the combat capability state of the artillery installation AU1.

$K_{mch} = 0.965$. Table 1 presents the values of time for performing respective actions by AU1 at the firing position. Table 2 shows the values of parameters affecting the combat capability of the installation when changing positions depending on the chosen road.

Table 1

Time intervals for performing corresponding actions during the execution of au1's task at the firing position and counteraction by the opposing side

Time for	Fire position (shooting)
Transition from the march state to the combat state at the firing position t_{mb}	5 mins
AU1 working on the target at the firing position for one shot t_{AU1}	15 s
AU2 working at the firing position against AU1 for one shot t_{AU2}	20 s
Transition from the combat state at the firing position to the march state t_{bm}	2 mins
The flight of the projectile over the distance from the firing position to the target determines the start of the opposing side's firing action at a stationary target t_{st}	12 000 m 35 s

Table 2

Parameters affecting the combat capability of the installation during position changes

Parameters influencing the combat capability of the installation and the total operation time depending on the chosen road for moving between positions	Road Number (j)		
	№ 1	№ 2	№ 3
March time when changing to another firing position $t_m(j), s$	180	720	1440
Decrease in AU1's combat capability due to barrel wear during transportation $k_{stv\_tr}(j)$	0.000025	0.000055	0.000075
Decrease in AU1's combat capability due to wear of the running part during transportation $k_{hod\_tr}(j)$	0.00074	0.00094	0.0024
Decrease in AU1's combat capability due to wear of the installation during the enemy's fire impact while in transit $k_{m\_tr}(j)$	0.000055	0.00003	0.000015

The method for calculating the model consists of a general algorithm, which is based on specialized additional algorithms. The ***"Positions"*** algorithm determines the current number of shells used at each position. The ***"Change of position"*** algorithm determines the sequence of road numbers used when changing positions from one to another. The ***"Combat capability"*** algorithm determines the final combat capability of AU1 upon completing the combat task with the current structure. The ***"Time"*** algorithm determines the total time for executing AU1's combat task with the current structure.

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

The general algorithm, based on the input data provided in Table 1 and Table 2, determines the current structure of task execution: $a(1); b(1); a(2); b(2); \ldots a(n); b(n)$ and calculates the final value of the combat capability of the artillery installation, considering its loss due to fire damage inflicted by the opposing artillery installation and its movement from one position to another for further execution of the target destruction task.

The general algorithm is presented in the following steps:

Step 1: Set $a\ (1) = \ldots a\ (n) = 1$, i.e., when there is one shot at each position and $k = n$ (where *k* is the number of the last position).

Step 2: Set initial variable values. Maximum combat capability value of all possible *structures* $P_{\max} = 0$, minimum combat capability value of all possible *structures* $P_{\min} = 1$, maximum total operation time $T_{\max} = 0$, and minimum total operation time $T_{\min} = 10^{10}$.

Step 3: Set $b(1) = \ldots b(k-1) = 1$, i.e., when position changes occur on road № 1.

Step 4: Using the ***"Combat capability"*** algorithm for the current *structure*, calculate the final combat capability of AU1.

Step 5: Using the ***"Time"*** algorithm, calculate the total time for AU1 to complete the combat task for the current *structure*.

Step 6: Compare the obtained combat capability values $PA(k)$ of AU1 for the current working structure with the current values of $P_{\max}, P_{\min}$, and the total operating time T at the positions and during position changes for the current structure with the current values of $T_{\max}, T_{\min}$. In case of better values, reassign to the current values and save in arrays the corresponding structures $aP_{\max}$ $[1\ldots n]$, $aP_{\max}[1\ldots n]$, $aP_{\min}[1\ldots n]$, $aP_{\max}$ $[1\ldots n]$, $aP_{\min}$ $[1\ldots n]$, $aT_{\max}$ $[1\ldots n]$, $aP_{\min}$ $[1\ldots n]$, $aT_{\max}$ $[1\ldots n]$, $aT_{\min}$ $[1\ldots n]$, $aT_{\max}$ $[1\ldots n]$, $aT_{\min}$ $[1\ldots n]$.

Step 7: As long as all $b\ (i) \neq 3\ (i = 1\ldots k-1)$, using the ***"Change of position"*** algorithm, form the next structure by changing the elements of the b array and proceed to ***Step 4***. Otherwise, move to the next step.

Step 8: *If* $a\ (1) \neq n$, then using the ***"Positions"*** algorithm, form the next structure and proceed to ***Step 3***. Otherwise, move to the next step.

Step 9: Using the ***"Combat Capability"*** algorithm, calculate the final combat capability of the current structure.

Step 10: Using the ***"Time"*** algorithm, calculate the total operating time of AU1 at the positions and the time for changing between positions for the current structure.

Step 11: Compare the obtained combat capability values $PA(k)$ of AU1 for the current working structure with the current values of $P_{\max}, P_{\min}$, and the total operating time T at the positions and during position changes for the current structure with the current values of $T_{\max}, T_{\min}$. In case of better values, reassign to the current values and save in arrays the corresponding structures $aP_{\max}[1\ldots n]$, $aP_{\min}[1\ldots n]$, $aP_{\max}[1\ldots n]$, $aP_{\min}[1\ldots n]$, $aT_{\max}[1\ldots n]$, $aT_{\min}[1\ldots n]$, $aT_{\max}$ $[1\ldots n]$, $aT_{\min}[1\ldots n]$.

Step 12: Output the calculation results. The algorithm is completed.

The ***"Positions"*** algorithm receives input data in the form of an array of values $a[1\ldots k]$ from the general algorithm.

Step 1: Find m – the number of the last non-zero element of the array a in the current task execution structure.

Step 2: Change the value of the element of the current structure array $a(m-1) = a(m-1) + 1$.

Step 3: *If* $a(m){=}1$, *then* $a(m){=}0$; otherwise, *if* $a(m){=}n{-}m$, then as long as $\sum_{j=1}^{m+i} a(j) \le n$, all elements from $a(m+1)$ to $a(m+i)$ are assigned the value 1; otherwise $a(m) = a(m) - 1$.

Step 4: Return the new values of the array elements $a[1\ldots k]$.

The ***"Change of Position"*** algorithm receives input data in the form of an array of values $b[1\ldots k-1]$ from the general algorithm.

Step 1: Find m – the number of the last element of the array b that equals either 1 or 2.

Step 2: *If* $m = k-1$, then $b\ (k-1) = b(k-1)+1$, otherwise $b\ (m) = b\ (m)+1$ and $b(i) = 1$ $(i = m+1 \ldots k-1)$.

Step 3: Return the new values of the array elements $b[1 \ldots k-1]$.

The ***"Combat Capability"*** algorithm receives input data in the form of an array of values $b[1 \ldots k-1]$ from the general algorithm.

Step 1: Set the initial combat capability of AU1 $PB(1) = K_{mch}$.

Step 2: *For* $i = 1 \ldots k$, perform ***Steps 3-7***.

Step 3: Calculate the number of shells d, fired from AU2 at AU1 to stop firing at the target:

$$d = \frac{a(i)t_{AU1} + t_{bm} - (t_{AU1} + t_{st})}{t_{AU2} + t_{st}}.$$

Step 4: Calculate the coefficient of reduction in combat capability of AU1 due to hits by shells from AU2 in AU1:

$$k_{vs} = \sum_{j=1}^{d} \frac{1}{j(j+1)}.$$

Step 5: Calculate the reduction in combat capability of AU1 due to combat work on destroying the target: $k_{br} = k_{stv} t_{AU1} a(i) + k_{hod} t_{AU1} a(i)$.

Step 6: Calculate the combat capability of AU1 after work on the i-th position: $PA_i = PB(i) - (k_{vs} + k_{br})$.

Step 7: Calculate the reduction in combat capability of AU1 when changing position as long as $i = 1 < k$: $PB(i+1) = PA_i - (k_{stv\_tr}(b(i)) + k_{hod\_tr}(b(i)) + k_{m\_tr}(b(i)))$.

Step 8: Return the combat capability value $PA(k)$ of the artillery installation AU1 for the current structure of its combat work.

The ***"Time"*** algorithm receives input data in the form of arrays of values $a[1 \ldots k]$, and $b[1 \ldots k-1]$ from the general algorithm.

Step 1: Set the initial time value *T*=0.

Step 2: *For* $i = 1 \ldots k$, perform ***Steps 3-4***.

Step 3: Calculate the total time of combat work and movements of AU1 including combat work at the i-th position: $T = T + t_{mb} + a(i)t_{AU1} + t_{bm}$.

Step 4: *If* $i \neq k$, calculate the total time of combat work and movements of AU1, considering the time for moving to position $i+1$: $T = T + t_m(b(i))$.

Step 5: Return the total time T for completing the combat task of AU1 for the current *structure*.

6. Research results

The study of the reduction in combat capability in the task setting (see 5.1) represents a large but finite number of possible variants for completing the combat task, which can be performed according to the rules of Pareto-oriented tasks on one hand, or dynamic programming tasks on the other. However, as it turned out, the number of input parameters (see Table 1 and Table 2) and the number of variable arguments in Table 3 and Table 4 allowed for obtaining all possible solutions through simple direct enumeration.

Table 3

Characteristics of variable arguments for solving the combat task by an artillery installation

Characteristic Name	Numerical Values			
1. Start of the opposing side's firing action after the first shot of the attacking sideї t_{st}, s	35	43	51	59
2. Number of shells required to destroy a stationary target n, pieces	4	6	8	10

It is important to note a significant property of the model for calculating the reduction in combat capability, as presented in ***Step 6*** of the ***"Combat Capability"*** algorithm. This calculated value can take a negative value, which from a technical point of view means the physical loss of the artillery installation, and the larger this value is in absolute terms, it means that the loss of equipment occurs earlier in the previous steps of task execution for the structure under consideration.

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

This aspect of the model highlights the criticality of the artillery installation's structural decisions in the task execution. The negative value in the calculation represents a critical loss in combat capability, signifying a potential turning point in the operational effectiveness of the artillery unit. Understanding and analyzing these points can provide valuable insights into the robustness and resilience of the artillery system, allowing for more effective strategies in real combat scenarios.

Table 4

Characteristics of options for variable arguments for solving the combat task by an artillery installation when changing the firing position

Characteristic name for reducing the combat capability of AU1	Modeling option *X*			Modeling option *Y*		
	Road number (j)					
	1	2	3	1	2	3
1) Due to barrel wear during transportation $k_{stv\_tr}(j)$	$2.5 \cdot 10^{-5}$	$5.5 \cdot 10^{-5}$	$7.5 \cdot 10^{-5}$	$2.5 \cdot 10^{-4}$	$5.5 \cdot 10^{-4}$	$7.5 \cdot 10^{-4}$
2) Due to wear of the running part during transportationi $k_{hod\_tr}(j)$	$7.4 \cdot 10^{-4}$	$9.4 \cdot 10^{-4}$	$2.4 \cdot 10^{-3}$	$7.4 \cdot 10^{-3}$	$9.4 \cdot 10^{-3}$	$2.4 \cdot 10^{-2}$
3) Due to wear of the insta-?lation during enemy fire impact while in transit $k_{m\_tr}(j)$	$5.5 \cdot 10^{-5}$	$3.0 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	$5.5 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$

When solving the given task, it was initially assumed that all shots are modeled as effective, as proposed in [23]. The probability of hitting the target with any artillery installation is greater than or equal to 0.5. The probability of reducing the combat capability of the attacking side's artillery installation due to hits by shells from the opposing side's artillery installation from shot to next shot is represented by the expression in step 4 of the ***"Combat capability"*** algorithm.

In Table 5, Table 6, Table 7 and Table 8 the results of the study for the best option out of the possible ones in terms of minimal loss of combat capability when executing a combat task over time are presented. For an understanding of the obtained characteristic and further analysis, the tables show values for both the best and worst variants.

Analysis of all tables with results allows us to state that for each required number of shells for hitting the target, there exists the best structure (see definition in 5.2), which is confirmed by the minimal reduction in combat capability and the time to complete the task.

There is also a method for the best structure to hit the target under the conditions of maximum preservation of combat capability while executing the combat task, but it does not always correspond to the minimum time of its execution. From another perspective, there exists the shortest time for executing the combat task, but the loss of combat capability value is quite significant, and in a number of cases, the artillery installation will be destroyed by the fire of the opposing side's artillery.

For the analysis of the considered variant (see Table 5), 262144 values of combat capability were calculated for each of the options under the condition of changing the calculation arguments. When executing a combat task with 10 shells, for modeling option *X*, the combat capability decreases from 0.965 to various values, but there is a fairly large number of results – 169209 values for the time of the start of the opposing side's firing action against the attacker in 35 seconds, where the values of current combat capability form a band from 0.775 to 0.825. Similarly, there are 257283 values for the time of 43 seconds, 261120 values for the time of 51 seconds, and 261936 values for the time of 59 seconds.

Analyzing the variant under consideration (see Table 5), 262144 combat capability values were calculated for each option under the condition of changing calculation arguments. In the task of 10 shots for modeling option *X*, the combat capability decreases from 0.965 to various values, but a significant number of results exist – 169209 values for the start time of the opposing side's firing action against the attacker in 35 seconds, where the values of current combat capability form a wider band from 0.575 to 0.825. Similarly, there are 257283 values for the time of 43 seconds, 261120 values for the time of 51 seconds, and 261936 values for the time of 59 seconds.

Table 5

Research results of the distribution of all possible combat capability variants for 10 shots for two modeling options

Distribution Intervals	Modeling option *X*				Modeling option *Y*			
	Start of firing action, t_{st} , s				Start of firing action, t_{st} , s			
	35	43	51	59	35	43	51	59
(0.075; 0.100]	0	0	0	0	37	0	0	0
(0.100; 0.125]	0	0	0	0	120	2	0	0
(0.125; 0.150]	202	7	1	0	53	5	1	0
(0.150; 0.175]	0	0	0	0	833	0	0	0
(0.175; 0.200]	0	0	0	0	6144	6	0	0
(0.200; 0.225]	0	0	0	0	23026	325	5	0
(0.225; 0.250]	0	0	0	0	35117	1350	176	4
(0.250; 0.275]	0	0	0	0	16902	2217	471	81
(0.275; 0.300]	120	0	0	0	1373	941	355	110
(0.300; 0.325]	83283	4851	1023	208	0	12	16	13
(0.575; 0.600]	0	0	0	0	1	1	1	1
(0.600; 0.625]	0	0	0	0	171	171	171	171
(0.625; 0.650]	0	0	0	0	1978	1986	1986	1986
(0.650; 0.675]	0	0	0	0	13363	14196	14196	14196
(0.675; 0.700]	0	0	0	0	44613	50766	50772	50772
(0.700; 0.725]	0	0	0	0	65746	89247	89567	89572
(0.725; 0.750]	0	0	0	0	37652	74350	75524	75696
(0.750; 0.775]	0	0	0	0	5670	24651	26397	26787
(0.775; 0.800]	8086	8206	8206	8206	15	1915	504	2749
(0.800; 0.825]	161123	249077	252914	253730	0	0	2	6
Structures and corresponding extreme values of combat capability								
For max value of combat capability	Sequence of the number of shots at positions							
	2;2;2;2;2	2; 4; 4	5; 5	4; 6	2;2;2;2;2	2; 4; 4	5; 5	4; 6
	Sequence of road numbers when changing positions							
	1;1;1;1	1;1	1	1	1;1;1;1	1;1	1	1
	Value of combat capability							
	0.8117	0.8134	0.8142	0.8142	0.7822	0.7986	0.8068	0.8068
	Time, s							
	2680	1590	1050	1050	2680	1590	1050	1050
For min value of combat capability	Sequence of the number of shots at positions							
	1;1;1;7	1;9	10	1;1;1;7	1;1;1;7	1;9	10	1;1;1;7
	Sequence of road numbers when changing positions							
	3; 3; 3	3		3; 3; 3	3; 3; 3	3		3; 3; 3
	Value of combat capability							
	0.1409	0.1458	0.1483	0.3075	0.0736	0.1234	0.1483	0.2403
	Time, s							
	5910	2310	510	5910	5910	2310	510	5910

For modeling option *Y*, the combat capability decreases from 0.965 to various values, but a significant number of results exist – 169209 values for the start time of 35 seconds, with the values of current combat capability forming a more extensive band from 0.575 to 0.825. Similarly, there are 257283 values for the time of 43 seconds, 261120 values for the time of 51 seconds, and 261936 val-

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

ues for the time of 59 seconds. For both modeling options *Y* and *X* at the start time of 35 seconds, there are negative combat capability values, totaling 9.330, while for other times, there are no instances of negative combat capability values.

Table 6

Research results of the distribution of all possible combat capability variants for 8 shots for two modeling options

Distribution Intervals	Modeling option *X*				Modeling option *Y*			
	Start of firing action, t_{st} , s				Start of firing action, t_{st} , s			
	35	43	51	59	35	43	51	59
(0.150; 0.200]	7	0	0	0	7	0	0	0
(0.200; 0.225]	0	0	0	0	6	0	0	0
(0.225; 0.250]	0	0	0	0	145	0	0	0
(0.250; 0.275]	0	0	0	0	1038	4	0	0
(0.275; 0.300]	0	0	0	0	2150	45	3	0
(0.300; 0.325]	0	0	0	0	974	119	19	2
(0.325; 0.350]	4353	208	40	7	40	40	18	5
(0.650; 0.675]	0	0	0	0	1	1	1	1
(0.675; 0.700]	0	0	0	0	21	21	21	21
(0.700; 0.725]	0	0	0	0	568	574	574	574
(0.725; 0.750]	0	0	0	0	2641	2786	2786	2786
(0.750; 0.775]	0	0	0	0	4928	5968	5972	5972
(0.775; 0.800]	0	0	0	0	3346	5514	5556	5559
(0.800; 0.825]	0	0	0	0	267	1274	1374	1391
(0.825; 0.850]	11772	16176	16344	16377	0	38	60	73
Structures and corresponding extreme values of combat capability								
For max value of combat capability	Sequence of the number of shots at positions							
	2;2;2;2	4;4	3;5	2;6	2;2;2;2	4;4	3;5	2;6
	Sequence of road numbers when changing positions							
	1;1;1	1	1	1	1;1;1	1	1	1
	Value of combat capability							
	0.8425	0.8442	0.8442	0.8442	0.8204	0.8368	0.8368	0.8368
	Time, s							
	2100	1020	1020	1020	2100	1020	1020	1020
For min value of combat capability	Sequence of the number of shots at positions							
	1;7	1;1;1;5	1;1;6	1;7	1;7	1;1;1;5	1;1;6	1;7
	Sequence of road numbers when changing positions							
	3	3;3;3	3;3	3	3	3;3;3	3;3	3
	Value of combat capability							
	0.1758	0.3375	0.34	0.3425	0.1534	0.2703	0.2952	0.3201
	Time, s							
	2280	5880	4080	2280	5880	4080	4080	2280

Regarding the execution of shots, the range spans from two shots at each of the first five combat positions to five shots from the first two combat positions. As for changing roads between positions, the best solutions correspond to the faster and more dangerous option 1. In terms of the ratio between the best and worst solutions, the ratios range from 4 to 10.

Similar qualitative results were obtained from the analysis of Table 5, Table 6, Table 7 and Table 8. It should be noted that the number of possible solutions decreased, the width of the band of results narrowed, and the ratio in comparing the best and worst solutions decreased to less than 2. However, with six shots, the number of possible firing positions increased.

Table 7

Research results of the distribution of all possible combat capability variants for 6 shots for two modeling options

Distribution Intervals	Modeling option *X*				Modeling option *Y*			
	Start of firing action, t_{st} , s				Start of firing action, t_{st} , s			
	35	43	51	59	35	43	51	59
(0.300; 0.325]	0	0	0	0	28	0	0	0
(0.325; 0.350]	0	0	0	0	121	0	0	0
(0.350; 0.375]	201	6	0	0	52	6	0	0
(0.375; 0.400]	1	1	1	0	1	1	1	0
(0.750; 0.775]	0	0	0	0	11	11	11	11
(0.775; 0.800]	0	0	0	0	155	155	155	155
(0.800; 0.825]	0	0	0	0	393	421	421	421
(0.825; 0.850]	0	0	0	0	250	371	371	371
(0.850; 0.875]	819	1017	1023	1023	10	59	65	65
(0.875; 0.900]	0	0	0	1	0	0	0	1
Structures and corresponding extreme values of combat capability								
For max value of combat capability	Sequence of the number of shots at positions							
	2;2;2	2;4	1;5	6	2;2;2	2;4	1;5	6
	Sequence of road numbers when changing positions							
	1;1	1	1		1;1	1	1	
	Value of combat capability							
	0.8734	0.8742	0.874	0.875	0.8586	0.8668	0.8668	0.875
	Time, s							
	1530	990	990	450	1530	990	990	450
For min value of combat capability	Sequence of the number of shots at positions							
	1;1;1;3	1;5	6	1;1;1;1;1;1	1;1;1;3	1;5	6	1;1;1;1;1;1
	Sequence of road numbers when changing positions							
	3;3;3	3		3;3;3;3;3	3;3;3	3		3;3;3;3;3
	Value of combat capability							
	0.3675	0.3725	0.375	0.8625	0.3003	0.3501	0.375	0.7505
	Time, s							
	5850	2250	450	9450	5850	2250	450	9450

Regarding the analysis of the time taken to complete the combat task based on the results obtained in Table 5, Table 6, Table 7 and Table 8, it can be stated that the best maximum option, which is ensured by the calculated structure for hitting the target, corresponds to the minimum time value. However, there are solutions for completing the combat task with 10 and 8 shells where this is not the case. Indeed, there is a significant reduction in time, but with the current combat capability value in the range of 0.1 to 0.2, which means the actual loss of the artillery installation.

The analysis of the results presented in Table 8 proved the possibility of completing the combat task with a maximum of two shots from each firing position. If the tactic of using 10 shots to destroy the target is oriented towards defensive tactics, then the tactic of destroying the target with 4 shots corresponds to offensive combat actions. This is confirmed by the worst results where the transfer between positions can be carried out on any roads with any characteristics of combat capability loss, which corresponds to offensive actions. Therefore, the tactic translated from English as “shoot and scoot” [21, 22] for the offense can be called “hide and shoot”.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

Table 8

Research results of the distribution of all possible combat capability variants for 4 shots for two modeling options

Distribution Intervals	Modeling option *X*				Modeling option *Y*			
	Start of firing action, t_{st} , s				Start of firing action, t_{st} , s			
	35	43	51	59	35	43	51	59
(0.375; 0.400]	0	0	0	0	6	0	0	0
(0.400; 0.425]	7	0	0	0	1	0	0	0
(0.825; 0.850]	0	0	0	0	7	7	7	7
(0.850 ;0.875]	0	0	0	0	28	28	28	28
(0.875; 0.900]	7	7	7	7	22	28	28	28
(0.900; 0.925]	50	57	57	57	0	1	1	1
Structures and corresponding extreme values of combat capability								
For max value of combat capability	Sequence of the number of shots at positions							
	2,2	4	4	4	2,2	4	4	4
	Sequence of road numbers when changing positions							
	1				1			
	Value of combat capability							
	0.9042	0.905	0.905	0.905	0.8968	0.905	0.905	0.905
	Time, s							
	960	420	420	420	960	960	960	960
For min value of combat capability	Sequence of the number of shots at positions							
	1;3	1;1;1;1	1;1;1;1	1;1;1;1	1;3	1;1;1;1	1;1;1;1	1;1;1;1
	Sequence of road numbers when changing positions							
	3	3;3;3	3;3;3	3;3;3	3	3;3;3	3;3;3	3;3;3
	Value of combat capability							
	0.4025	0.8975	0.8975	0.8975	0.3801	0.8303	0.8303	0.8303
	Time, s							
	2220	5820	5820	5820	2220	5820	5820	5820

Conclusions

1. A model has been developed for managing the combat operations of an artillery unit that solves the task of destroying a target with a specified number of shells while changing firing positions to reduce the likelihood of the unit being hit by enemy artillery. The dynamics of the system interaction "attacking artillery unit – target – opposing artillery unit" are considered in the processes of action. The model determines the reduction in combat capability over time due to sudden failures, wear failures during combat operations, and failures due to destruction by the opposing side. The model assumes that all shots are effective, i.e., the probability of hitting each target is more than 50 %. The model assumes that the number of firing positions equals the number of shots required to hit the target, with a minimum of one shot per firing position. The model of position change does not include returning to previous positions. Simulation of movement from one position to another occurs sequentially along one of the roads of varying quality and different likelihood of being hit by the opposing side.

2. A method has been developed to find the solution for the state of execution of a combat task by an artillery unit based on the proposed model. The concept of the current structure of task execution, which is a sequence of the number of shots at each of the firing positions and the numbers of roads used to change positions, has been introduced. The method for finding the solution to the state of execution of a combat task by an artillery unit can be attributed to solving Pareto-oriented tasks or dynamic programming tasks. However, the number of input parameters and the number of variable arguments allowed all possible solutions to be obtained by direct enumeration. The calculation method of the model consists of a general algorithm, which is based on specialized additional algorithms. The ***"Positions"*** algorithm determines the current number of shells used at each position. The ***"Change position"*** algorithm determines the sequence of road numbers used when changing positions from one to another. The ***"Combat capability"*** algorithm determines the final combat capability of the artillery

unit upon completion of the combat task in its current structure. The ***"Time"*** algorithm determines the total time taken to complete the combat task in its current structure.

3. For the proposed tactic of executing a combat task by an artillery unit "hide and shoot", it is necessary to find the best solutions for a possible group of variable arguments, taking into account the relative value of the attacking artillery unit and the target for which the combat task is being executed, and the losses for the attacking side that arise if the target is not destroyed.

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Received October 16, 2023

Accepted December 10, 2023