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Development and optimization of simulation models and methods for controlling virtual artillery units in game scenarios

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ABSTRACT

In the realm of modern video game development, special attention is given to the simulation of artillery systems, which play a crucial role in various military-themed games. This research presents a mathematical model for simulating the actions of a virtual artillery system. The model is designed to manage the execution of combat tasks, including targeting destruction with a specified number of shells and incorporating the strategic movement between firing positions to minimize detection and attack by enemy forces in the game. The model presumes that all shots are effective and equates the number of firing positions to the number of shots, with a minimum of one shot per position. The model's dynamics do not allow for returning to previous positions, adding a layer of complexity and realism to the gameplay. Movement simulations between positions are designed along virtual roads of varying quality, enhancing the strategic elements of the game. A method for determining the optimal strategy for the artillery system's actions has been developed, introducing the concept of the current structure of combat task execution. This problem-solving approach falls within the realm of Pareto-oriented tasks or dynamic programming challenges. The computational method of the model is based on a general algorithm, underpinned by specialized additional algorithms. Results from this model demonstrate the feasibility of completing combat tasks effectively, with a maximum of two shots per firing position. The research differentiates between defensive and offensive tactics in gameplay, suggesting that while a strategy involving ten shots per target aligns with defensive gameplay, a strategy with four shots per target aligns with offensive actions. Consequently, the "shot-and-scoot" tactic in an offensive context can be aptly termed as “hid-and-shot”.

Keywords: Virtual artillery system; game simulation; current structure; strategy optimization; dynamic programming; algorithm; automated control in games; military simulation in video games

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1. INTRODUCTION

In today's world of video games, artillery and tactical missile units are frequently used to create realistic combat scenarios that simulate a variety of tactical and strategic situations. Modern gaming artillery units offer players tasks similar to real tactical missile operations, but within a virtual environment. The analysis of scenarios in various video games demonstrates the importance of artillery units in solving tactical tasks, providing players with engaging and dynamic gameplay.

In modern game design, the speed of development in virtual battles and the intensity of actions [1] offer players a variety of strategies and tactical maneuvers [2]. A key aspect is the development of game mechanics that allow players to manage virtual artillery units, adapt to changing conditions, and execute tasks with minimal losses.

Any tactic in the gaming world is based on the theory and practice of planning and conducting operations in various scenarios. Preparing a scenario requires understanding the patterns of battle; developing strategies and tactics that help players achieve their goals. Mathematical modeling [3] is particularly important, allowing for accurate reproduction of different aspects of combat actions and influencing the game process, further enhancing the realism of gameplay.

Developing game scenarios often includes analyzing simulation models where players can use various types of weapons and manage resources [4]. An important component is modeling the interaction between artillery units [5, 6] and determining optimal strategies for mission execution.

This article analyzes game models where artillery units are key elements of gameplay. It explores tactical aspects of managing virtual artillery units (VAU), considering the need for constant movement and adaptation to the changing conditions of the virtual combat environment (VCE). Special attention is given to developing strategies that ensure maximum efficiency of attacking units while maintaining their combat readiness and responding to the actions of the opposing side.

2. LITERATURE REVIEW

A crucial component in developing game scenarios is the analysis of tactics used by virtual artillery units (VAU), especially during maneuverable gameplay [7]. The mobility of VAUs is key to ensuring effective and dynamic gameplay, as it allows players to adapt to the changing conditions of virtual combat.

Literature indicates various game models that simulate conditions for changing positions for VAU firing. One such model is increasing shooting accuracy through constant fire adjustment based on the results of previous shots [8].

On the other hand, the longer a VAU stays in one position, the greater the probability of a counterattack by enemy forces. This necessitates increased maneuverability of VAUs, as well as a "shoot and scoot" tactic, where artillery units change their position immediately after firing.

This tactic minimizes losses and maintains the combat readiness of units in the game process. Modern game models of artillery units have high rates of fire and mobility, allowing players to move quickly between positions and make repeated shots.

The “hide and seek” tactic is also considered, used in offensive actions where artillery units of the attacking side can perform several cycles of shooting and changing position [9]. Literature also discusses various models considering the rate of fire and accuracy of artillery units [10], aiming processes, errors, and the probability of hitting the target.

Particular attention is paid to developing methods and models for optimizing the movement of VAUs in virtual reality environments, including choosing firing positions and routes of movement, considering the game's topology. Thus, modern research in game design and simulations emphasizes the importance of continuous development and improvement of VAU game models for quality and realistic gameplay [11].

Particularly important are studies focused on modeling the movement of virtual artillery units in game scenarios [12]. These works propose different methods for choosing positions for virtual fire and routes of movement, considering the peculiarities of the game landscape.

Markov models are commonly used to simulate the actions of artillery units in games. One such model assesses the effectiveness of game strategies, particularly considering the wear and tear of VAUs and time losses due to movement, but does not take into account the decrease in combat capability due to virtual enemy fire.

Another method of analysis is based on a Markov model that determines states when VAUs should change their position to reduce losses from enemy fire. This model includes an algorithm where the attacking side initiates fire action from an unknown position, while the enemy side tries to detect its position based on the analysis of fire actions. Such models help game developers create more complex and realistic game scenarios, where players need to consider tactical decisions to maintain the combat readiness of their virtual units.

Other studies concentrate on determining the optimal timing for attacks and minimizing losses of virtual artillery units [13, 14]. These include modeling time windows for attacks and assessing the effectiveness of various game strategies.

Modern game models also demonstrate improvements in simulating counter-battery warfare, allowing for the creation of more complex and engaging game mechanics. The results of such research are important for game design development, especially in the context of modeling artillery battles and developing strategies for games [15].

The analysis of literature sources has classified the relevance of this research, which lies in the need to develop and improve game models and methods that effectively simulate VAU actions in a virtual environment. Considering the current trends in the game industry, including the optimization of algorithms for determining movements and interactions of VAUs in the variable conditions of video games, relevance is determined by several key aspects.

The growing popularity of military simulations in video games is evidenced by the constant demand for realistic military simulations in the gaming industry. Developing detailed models for VAUs provides players with a more immersive and realistic gaming experience.

The need to improve tactical game elements to enhance competitiveness by reproducing realistic changes in VAU properties requires careful modeling of tactical elements [16]. Developing effective algorithms and methods allows players to use complex tactics and strategies in games.

Innovations in gaming technologies of the modern gaming industry demand constant improvement of game mechanics. Developing new models for VAUs contributes to innovations in game design and expands possibilities for game developers [17].

The application of modern practices in mathematical and computer modeling for VAU simulation [18] opens a new direction for more accurate and effective gaming solutions, enhancing the quality of gaming products and increasing their sales. Ensuring realistic changes in properties and reactions of VAUs [19] enhances player engagement and dynamic immersion in the gameplay.

Thus, this research is of great significance for the development of the gaming industry, especially in the context of reproducing realistic military scenarios and tactics in video games.

3. THE OBJECTIVE

The objective of this article is to develop and improve tactical models and methods for simulating the resolution of VAU (Virtual Artillery Unit) tasks within the gaming process. This includes creating algorithms and mechanics that enable players to efficiently manage VAUs, optimize their positioning, select targets, and time responses in the Virtual Combat Environment (VCE). The practical significance of this work lies in enhancing the gaming experience by providing players with a realistic understanding of the strategic and tactical aspects of managing VAUs.

– To improve the simulation model for gaming applications, it is necessary to develop and refine the mathematical model for controlling a virtual artillery unit in the gaming process. This will effectively represent target selection and resource management, including calculating the current state of combat readiness of the VAU, thereby increasing the realism of the game.

– Improving the decision-making method in the gaming scenario allows players to determine the optimal action plan for VAUs, considering the actions of enemy (opposing) forces. This is achieved by possible changes in firing positions and developing strategies for effective task execution in the variable conditions of the VCE.

4. MODELING STATES OF VIRTUAL ARTILLERY UNITS (VAUS)

The VAU model can be adapted for simulating various types of artillery weapons in games, from mortars to heavy self-propelled units, by altering settings and parameters. This model is represented as a Markov chain, allowing the simulation of different states of artillery units in gameplay and comparing the effectiveness of various fire control strategies and algorithms.

In the virtual environment, each time a unit occupies a new position; it remains undetected by the virtual enemy until it opens fire. The simulation of passive acoustic radars in the game enables the determination of the unit's location after the first shot.

The model also includes algorithms determining the probability of detection based on the number of shots fired. The distribution of targets for shelling is random, following a Poisson distribution, mimicking the randomness of real-life combat scenarios.

Movement between positions is crucial for maintaining the unit's combat readiness. If detected, the model predicts a high probability of quickly moving to a new position to avoid enemy fire.

During movement, the unit cannot perform firing tasks, adding realism to the gameplay. The model also accounts for situations where the artillery unit may suffer losses or damage, temporarily or permanently losing its combat capability. This approach allows the modeling of various tactical scenarios and realistically reproducing combat actions in the gaming environment, providing players with a deep and immersive experience.

In the context of game modeling, essential data for simulating the actions of virtual artillery units include the number of targets, the speed of their detection, the number of shots needed to hit a target, the probability of the unit being detected during firing, the average time until an attack by the opposing side, the speed of recovery after an attack, the speed of movement between positions, the probability of being attacked during movement, the speed of the opposing side's reaction, and the speed of leaving a position after deciding to change it.

The “combat readiness” of a virtual artillery unit may include its ability to withstand virtual impacts from opposing forces, including mechanical loads, vibrations, shocks, and other factors that simulate real combat conditions. The mathematical model of combat readiness may include calculations of the failure intensity of the unit's components under different conditions. This allows game developers to precisely adjust the behavior of units in the virtual environment, considering different stress levels and impacts.

The assessment of combat readiness in the model can be determined by two probabilistic components: sudden failures and wear-related failures. Sudden failures can be modeled by an exponential law, where reliability is represented as a function of time, considering the intensity of sudden failures. This allows the simulation of various scenarios in games where artillery units can face unexpected problems, as in real combat.

Such detailed modeling enables the creation of games that accurately replicate the complexity and unpredictability of military actions, providing players with a deeper and more immersive gaming experience.

In the context of video game simulations, the modeling of artillery unit failures is crucial for realism. Sudden failures within the game environment are represented by an exponential law, where the combat capability of a virtual artillery unit is depicted as failure-free operation. The value of this quantity can be mathematically expressed as:

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

where λ is the intensity of sudden failures. These failures can affect various aspects of the game's artillery unit, such as the initial velocity of the projectile, the speed of moving the unit between firing positions, and the energetic characteristics of the artillery charge, which includes the strength of the powder.

Generally, the failure intensity in the game's model can be defined as:

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

Moreover, for any distribution law in the game's environment, the following relationship holds:

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

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

In normal in-game combat operation, following the exponential law, the failure intensity is constant. However, as the combat capability of the artillery unit decreases, the failure intensity begins to rise, and failures due to the loss of combat capability, which are typically modeled by the normal distribution law in technical practice, 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 in the game. The standard deviation from the average combat capability is given by:

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

where N is the number of failures over time t.

The joint probability of a virtual artillery unit's combat capability, considering both sudden failures and failures due to loss of combat capability from the start time $t_0 = 0$, to time t, is determined by:

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

If a virtual artillery unit has partially lost its combat capability in the game, the joint possibility is calculated as:

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

While formula (2) provides a theoretical framework to determine the combat capability of a virtual artillery unit at any given time, it has limitations in the gaming context. For instance, irregular operation in a game leads to accelerated virtual wear and tear. Field observations in the game show that failure intensity is highly dependent on how well the artillery unit operates according to its in-game specifications. Exceeding the nominal load leads to a sharp increase in failure intensity and this expression does not account for a sudden drop in combat capability if the unit is hit by enemy forces. Conversely, failure intensity decreases when the load is lower than nominal.

Considering these factors, which primarily affect failure intensity in the game, the following expression is used for modeling reliability:

$$P(t) = e^{-\int_T^{T+t}\lambda dt} = e^{-\lambda_в t+\int_T^{T+t}\lambda_u dt}, \qquad (3)$$

where $\lambda_в$ is the intensity of sudden failures, and λ_u is the intensity of failures due to the loss of combat capability.

To determine the intensity of failures due to loss of combat capability in the game, the following approach can be utilized. From formula (1), in general, failure intensity is determined as

$$\lambda = f(t)/P(t)$$

Consider a scenario in the game simulation where the combat capability of the artillery unit can be increased by a certain value Δt at each iteration of the current working time. Then, the current intensity of failures due to loss of combat capability is determined using formula (3). Suppose, during a particular iteration, the artillery unit is subjected to forced impact in the game, leading to an increased loss of its combat capability. To model this increased loss, Δt is added to the current time of the unit, corresponding to the reduced system combat capability. The expression $P(t) = e^{-\lambda t}$ corresponds to the theoretical model of changing combat capability over time for sudden failures. The expression $P(t) = \frac{P_u(T+t)}{P_u(t)}$ describes the change in combat capability during combat operations in the game, excluding destruction by enemy forces.

5. MAIN PART OF THE RESEARCH

5.1. Simulation model of the VAU for game applications

Let's develop a model for controlling the combat operations of a VAU in a video game scenario. VAU1 is tasked with destroying a stationary target with n shells while fully prepared for firing and with the ability to change firing positions to reduce the likelihood of being targeted by VAU2.

For this simulation, we assume that the number of firing positions equals the number of shots, n, necessary to hit the target. Furthermore, the minimum number of shots from a firing position is one, meaning at least one shot must be made from the current position. Changing positions does not involve returning to previous ones. Transitioning from one position to another along one of the s roads of varying quality and different likelihood of being targeted by the opposing side is sequential. VAU1 assumes the impossibility of VAU2's movement and targeting.

We set the initial state of VAU1's virtual combat capability as $Kmch$. The mathematical model is structured to determine the current combat capability of VAU, considering its loss due to enemy fire and its movement from one position to another to continue the mission.

The dynamics of VAU1 and VAU2 are considered in the following virtual processes of action (A, B, and C). For VAU1, A – at a firing position: (A1 – transition from marching to combat state; A2 – combat work of AU1 on target; A3 – transition from combat to marching state). B – Changing position. For VAU2, C – at a firing position: (C1 – combat work of AU2 on the stationary target of AU1 after its first shot until the end of the transition from combat to marching state; C2 – combat work of VAU2 on the moving target VAU1 while changing its firing position).

Events occurring in virtual time:

− event A1 is characterized by the time interval of VAU1's transition from marching to combat state at the firing position t_{mb};

− event A2 is characterized by the time interval VAU1 works on the target at the firing position for one shot t_{VAU1}; for multiple shots, the total time increases;

− event A3 is characterized by the time interval of VAU1's transition from combat to marching state t_{bm};

− event B is characterized by the time interval of the march when changing the firing position to another t_{m}^{j} along the $j-th$ road ($j = 1...s$);

– event C1 is characterized by the time interval VAU2 works on the target at the firing position for one shot t_{VAU2} 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 $t_{\text{м}}^{j}$ along the $j-th$ road ($j = 1...s$) and the time interval of VAU1's transition from marching to combat state t_{bm}.

The current state of VAU1's combat capability is influenced by all events that reduce it.

The effect of event A2 on the change in combat capability of VAU1 is characterized by the degree of reduction due to barrel wear k_i^{barr} for one shot at the firing position and the reduction due to wear of the VAU1's running gear k_i^{run} for one shot.

The effect of event B on changing the combat capability of VAU1 during transportation along the $j-th$ road ($j = 1..s$) is characterized by the reduction due to barrel wear $k_{\text{barr\_wear}}^{j}$ and the reduction due to wear of the running gear $k_{\text{run\_wear}}^{j}$.

The effect of event C1 on the change in combat capability of VAU1 is characterized by the reduction k_{red} due to hits from VAU2 on VAU1 depending on the number of shells d fired from VAU2 at VAU1 to stop firing at the target:

$$k_{\text{red}} = \sum_{j=1}^{d} \frac{1}{j(j+1)},$$

The number of shells d is calculated using the formula, assuming VAU1 makes a_i shots at the target while conducting combat work at the $i-th$ position ($i = 1..n$):

$$d = INT\left(\frac{a_i \cdot t_{\text{VAU1}} + t_{\text{bm}} - (t_{\text{VAU1}} + t_{\text{st}})}{t_{\text{VAU2}} + t_{\text{st}}}\right),$$

where INT () is the function that extracts the integer part of the obtained real number.

The effect of event C2 on changing the combat capability of VAU1 is characterized by the reduction $k_{\text{m\_tr}}^{j}$ due to wear of the unit under enemy fire during transportation along the $j-th$ road ($j = 1,\ldots,s$).

Therefore, the value of VAU1's combat capability PA_i after combat work at the $i-th$ position is calculated by the formula:

$$PA_i = PB_{i-1} - (k_{\text{red}} + k_{\text{barr}} \cdot t_{\text{VAU1}} \cdot a_i + k_{\text{run}} \cdot t_{\text{VAU1}} \cdot a_i),$$

where PB_{i-1} is the combat capability of VAU1 after changing from position $i-1$ to position i, with $PB_0 = Kmch$.

The reduction in combat capability of VAU1 when changing from position i to position $i+1$ ($i = 1..n-1$) is calculated by the formula:

$$PB_i = PA_i - \left(k_{\text{barr\_tr}}^{j} + k_{\text{run\_tr}}^{j} + k_{\text{m\_tr}}^{j}\right).$$

The combat capability of VAU1 after completing the combat task with n shots, assuming the last $n-th$ shot is made at position k ($k \le n$), is equal to PA_i.

5.2. Method of solving the model in a gaming scenario

To develop a computational method for determining the state of execution of a combat task by an attacking side's artillery unit (VAU1), considering the opposing artillery unit's (VAU2) fire on the current and changing firing positions, we 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. Another array, $b[1 \ldots n-1]$, is defined, where each element $b(j)$ represents one of three roads used when changing from 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 roads used for changing positions: (1); $b(1)$; $a(2)$; $b(2)$; ... $a(n)$..

We set the initial state of VAU1's combat capability as $Kmch = 0{,}965$. Table 1 presents the time values for performing corresponding actions by VAU1 at the firing position. Table 2 shows the parameter values that impact the virtual combat capability of the unit when changing positions, depending on the chosen road.

Table 1. **Time intervals for performing corresponding actions during the execution of VAU1's task at the firing position**

Time for	Fire position (shooting)
Transition from the march state to the combat state at the firing position t_{mb}	5 mins
VAU1 working on the target at the firing position for one shot t_{VAU1}	15 s
VAU2 working at the firing position against AU1 for one shot t_{VAU2}	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

Source: **compiled by the authors**

Table 2. **Parameters affecting VAU1's**

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)		
	No. 1	No. 2	No. 3
March time when changing to another firing position $t_{\text{m}}(j), s$	180	720	1440
Decrease in VAU1's combat capability due to barrel wear during transportation $k_{\text{barr\_tr}}(j)$	0.000025	0.000055	0.000075
Decrease in VAU1's combat capability due to wear of the running part during transportation $k_{\text{run\_tr}}(j)$	0.00074	0.00094	0.0024
Decrease in VAU1's combat capability due to wear of the installation during the enemy's fire impact while in transit $k_{\text{m\_tr}}(j)$	0.000055	0.00003	0.000015

Source: **compiled by the authors**

The method for calculating the model consists of a general algorithm 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. The "***Combat capability***" algorithm determines the final combat capability of VAU1 upon completing the combat task with the current structure. The "***Time***" algorithm calculates the total time for executing VAU1's combat task with the current structure.

The general algorithm, based on the input data from Tables 1 and 2, determines the current structure of task execution: $a(1)$; $b(1)$; $a(2)$; $b(2)$; ..., $a(n)$; $b(n)$ and calculates the final value of the combat capability of the artillery installation. This calculation considers 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:

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

2: Set initial variable values. Maximum combat capability value of all possible *structures* $Pmax = 0$, minimum combat capability value of all possible *structures* $Pmin = 1$, maximum total operation time $Tmax = 0$, and minimum total operation time $Tmin =\ 10^{10}$.

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

4: Using the ***"Combat capability"*** algorithm for the current *structure*, calculate the final combat capability of VAU1.

5: Using the ***"Time"*** algorithm, calculate the total time for VAU1 to complete the combat task for the current *structure*.

6: Compare the obtained combat capability values $PA(k)$ of VAU1 for the current working structure with the current values of $Pmax$, $Pmin$, and the total operating time T at the positions and during position changes for the current structure with the current values of $Tmax, Tmin$. In case of better values, reassign to the current values and save in arrays the corresponding structures $aPmax\ [1 \dots n]$, $aPmin\ [1 \dots n]$, $aPmax\ [1 \dots n]$, $aPmin\ [1 \dots n], aTmax\ [1 \dots n]$, $aTmin\ [1 \dots n]$, $aTmax\ [1 \dots n]$, $aTmin\ [1 \dots n]$.

7: As long as all $b\ (i) \neq 3\ (i = 1 \dots k-1)$, 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.

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.

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

10: Using the ***"Time"*** algorithm, calculate the total operating time of VAU1 at the positions and the time for changing between positions for the current structure.

11: Compare the obtained combat capability values $PA(k)$ of VAU1 for the current working structure with the current values of $Pmax$, $Pmin$, and the total operating time T at the positions and during position changes for the current structure with the current values of $Tmax$, $Tmin$. In case of better values, reassign to the current values and save in arrays the corresponding structures $aPmax\ [1 \dots n]$, $aPmin\ [1 \dots n]$, $aPmax\ [1 \dots n]$, $aPmin\ [1 \dots n], aTmax\ [1 \dots n]$, $aTmin\ [1 \dots n]$, $aTmax\ [1 \dots n]$, $aTmin\ [1 \dots n]$.

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

The "***Positions"*** algorithm in a gaming scenario. The "***Positions"*** algorithm, integral to a gaming environment, processes input data in the form of an array of values $a[1 \dots k]$ provided by the general algorithm. The steps are as follows:

1: Determine m – the position of the last non-zero element in the array a, which corresponds to the current task execution structure within the game.

2: Alter the value of the $a(m-1)$ element in the array to $a(m-1)+1$, adjusting the number of shots at position $(m-1)$.

3: $If\ a(m)\ equals\ 1, set\ a(m)\ to\ 0$. Conversely, $if\ a(m)\ equals\ n - m$, and provided the sum of elements $from\ a(m+1)\ to\ a(m+i)$ is less than or equal to n, set all these elements to 1. Otherwise, decrease $a(m)$ by 1.

4: Convey the newly adjusted values of the array elements $a[1 \dots k]$ for further processing.

The "***Change of Position"*** algorithm in a gaming scenario. This algorithm processes data in the form of an array $b[1 \dots k-1]$ and includes the following steps:

1: Determine m as the position of the last element in array b that equals either 1 or 2.

2: $If\ m\ equals\ k-1$, increase $b(k-1)$ by 1. Otherwise, increase $b(m)$ by 1 and set all elements $b(i)$ where i ranges $from\ m+1$ to $k-1$ to 1.

3: Provide the updated values of the array elements $b[1 \dots k-1]$ for subsequent use in the simulation.

The "***Combat Capability"*** algorithm in a gaming scenario. This algorithm, crucial for simulating the combat efficiency of artillery units, involves:

1: Establish the initial combat capability of VAU1 as $PB(1) = Kmch$.

2: For each position i ranging from 1 to k, perform the following steps:

3: Calculate d, the number of shells fired from VAU2 at VAU1 to halt its firing at the target:

$$d = \frac{a(i) \cdot t_{\text{VAU1}} + t_{\text{bm}} - (t_{\text{VAU1}} + t_{\text{st}})}{t_{\text{VAU2}} + t_{\text{st}}}.$$

4: Determine $k_{вс}$, the coefficient of reduction in VAU1's combat capability due to hits by shells from VAU2:

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

5: Determine $k_{бр}$, the reduction in combat capability of VAU1 due to its combat actions:

$$k_{бр} = k_{\text{barr}} \cdot t_{VAU1} \cdot a(i) + k_{\text{run}} \cdot t_{VAU1} \cdot a(i)$$

6: Calculate PA_i, the combat capability of VAU1 after its actions at the $i-th$ position:

$$PA_i = PB(i) - (k_{вс} + k_{бр})$$

7: $For\ i < k$, calculate $PB(i+1)$, the combat capability of VAU1 after changing its position:

$$PB(i+1) = PA_i - \left(k_{\text{barr\_tr}}(b(i)) + k_{\text{run\_tr}}(b(i)) + k_{\text{m\_tr}}(b(i))\right)$$

8: Provide the combat capability value $PA(k)$ of VAU1 for the current structure of its combat operations.

The "***Time***" algorithm in a gaming scenario. This algorithm, critical for time control in combat simulations, involves the following steps:

1: Set the initial time value $T = 0$.

2: For each position i from 1 to k, perform these actions:

3: Add to T the total time spent by VAU1 in combat and movement at the $i-$th position:

$$T = T + t_{mb} + a(i) \cdot t_{VAU1} + t_{bm}$$

4: For $i \neq k$, factor in the time spent moving to position $i+1$.

$$T = T + t_m(b(i)).$$

5: Return the total time T for completing the combat task of VAU1 for the current *structure*.

6. ANALYSIS OF COMBAT CAPABILITYREDUCTION IN GAMING SCENARIOS

In the gaming scenario, the study of combat capability reduction in task execution (see section 5.1) covers a broad range of possible variants for completing combat tasks. These variants can align with the principles of Pareto-oriented tasks or dynamic programming. The study found that the number of input parameters (refer to Table 1 and Table 2) and the variability in Table 3 and Table 4 enabled finding all possible solutions through direct enumeration. A key aspect of the model for calculating combat capability reduction, as outlined in step 6 of the "***Combat Capability***" algorithm, is that the computed value can be negative. In a gaming context, this indicates the virtual destruction of the artillery installation. A larger absolute value suggests earlier equipment loss during previous task execution steps for the given structure.

Table 3. **Characteristics of Variable Arguments**

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

Source: **compiled by the authors**

Table 4. **Characteristics of options for variable arguments**

Characteristic name for reducing the combat capability of VAU1	Modeling option X			Modeling option Y		
	Road number (j)					
	1	2	3	1	2	3
Due to barrel wear during transportation $k_{barr\_tr}(j)$	$2.5 \cdot 10^{-5}$	$5.5 \cdot 10^{-5}$	$7.5 \cdot 10^{-5}$	$2.5 \cdot 10^{-4}$	$5.5 \cdot 10^{-4}$	$7.5 \cdot 10^{-4}$
Due to wear of the running part during transportation $k_{run\_tr}(j)$	$7.4 \cdot 10^{-4}$	$9.4 \cdot 10^{-4}$	$2.4 \cdot 10^{-3}$	$7.4 \cdot 10^{-3}$	$9.4 \cdot 10^{-3}$	$2.4 \cdot 10^{-2}$
Due to wear of the installation during enemy fire impact while in transit $k_{m\_tr}(j)$	$5.5 \cdot 10^{-5}$	$3.0 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	$5.5 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$

Source: **compiled by the authors**

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This model aspect emphasizes the importance of structural decisions in artillery installation operation within the game. The negative value in calculations represents a crucial loss in combat capability, marking a potential shift in the unit's operational effectiveness. Understanding these critical points can offer insights into the artillery system's resilience, guiding more effective strategies in simulated combat scenarios.

Initially, the study assumed that all shots are modeled as effective, with a hit probability for any artillery installation being greater than or equal to 0.5. The probability of the attacking artillery unit's combat capability being reduced due to enemy fire is expressed in step 4 of the "***Combat Capability***" algorithm.

Table 5 to Table 8 present the study results for the best option among all possible ones in terms of minimal loss of combat capability over time. These tables also include values for both the best and worst variants to provide a comprehensive understanding and facilitate further analysis.

Analyzing these tables reveals that for each required number of shells to hit the target, there is an optimal structure that minimizes combat capability reduction and task completion time. This structure, however, does not always correlate with the shortest execution time. In some instances, the quickest task execution results in significant combat capability loss, potentially leading to the artillery installation's destruction by enemy fire.

For instance, analyzing option X in Table 5, with a task of 10 shots, shows a decrease in combat capability from 0.965 to varying values. Notably, there are numerous results – 169209 values for a start time of 35 seconds, where combat capability values range from 0.575 to 0.825. Similar patterns are observed for start times of 43, 51 and 59 seconds.

For option Y, the decrease in combat capability follows a similar pattern, but with distinct ranges of values at various start times. Notably, at the 35-second start time, both options Y and X show negative combat capability values, indicating the virtual destruction of the artillery installation.

Table 5. **Research results 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
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		0.8142		0.7822	0.7986	0.8068	0.8068
	Time, s							
	2680		1050		2680	1590	1050	1050
For min value of combat capability	Sequence of the number of shots at positions							
	1;1;1;7						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		0.1483		0.0736	0.1234	0.1483	0.2403
	Time, s							
	5910		510		5910	2310	510	5910

Source: **compiled by the authors**

Table 6. **Research results 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			59
Structures and corresponding extreme values of combat capability								
For max value of combat capability								
								2;6
								1
	Value of combat capability							
			0.8442		0.8204	0.8368		0.8368
	Time, s							
			1020		2100	1020		1020
For min value of combat capability								
								1;7
								3
	Value of combat capability							
		0.3375	0.34		0.1534	0.2703		0.3201
	Time, s							
		5880	4080		5880	4080		2280

Source: **compiled by the authors**

In terms of shot execution, the best solutions range from two shots at each of the first five positions to five shots from the first two positions. The optimal road changes between positions usually involve the quicker and riskier option 1. The ratio between the best and worst solutions varies, highlighting the strategic diversity available in the game.

Analysis of Table 5 and Table 8 consistently shows that the number of possible solutions decreases as the number of shots increases, narrowing the range of results and reducing the ratio of best to worst solutions. However, with six shots, the number of possible firing positions increases, adding complexity to the scenario.

Analyzing the time required to complete the combat task based on these results reveals that the best maximum options, as determined by the calculated structures, correspond to the minimal time values. However, certain solutions for completing tasks with 10 and 8 shells deviate from this trend. These cases show a significant reduction in time but with combat capability values in the range of 0.1 to 0.2, indicating the practical loss of the artillery installation.

Table 8 confirms the feasibility of completing combat tasks with a maximum of two shots per position. A tactic using 10 shots, oriented towards defense, contrasts with a 4-shot tactic suited for offensive actions. This is supported by the worst-case scenarios, where position changes can occur on any road with varying combat capability loss characteristics, aligning with offensive strategies. Hence, the tactic known as “shoot and scoot” in offensive contexts can be appropriately termed “hide and shoot” in the game's strategic framework.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.

Table 7. **Research results 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
Structures and corresponding extreme values of combat capability								
For max value of combat capability	Sequence of the number of shots at positions							
							1;5	6
	Sequence of road numbers when changing positions							
	1;1					1	1	
	Value of combat capability							
			0.874		0.8586	0.8668	0.8668	0.875
	Time, s							
			990		1530	990	990	450
For min value of combat capability	Sequence of the number of shots at positions							
							6	1;1;1;1;1;1
	Sequence of road numbers when changing positions							
								3;3;3;3;3
	Value of combat capability							
		0.3725	0.375		0.3003	0.3501	0.375	0.7505
	Time, s							
		2250	450		5850	2250	450	9450

Source: **compiled by the authors**

Table 8. **Research results 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
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							
	Value of combat capability							
		0.905	0.905		0.8968	0.905	0.905	0.905
	Time, s							
		420	420		960	960	960	960
For min value of combat capability	Sequence of the number of shots at positions							
							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
	Value of combat capability							
		0.8975	0.8975		0.3801	0.8303	0.8303	0.8303
	Time, s							
		5820	5820		2220	5820	5820	5820

Source: **compiled by the authors**

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.

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 values 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.

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.

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”.

7. ANALYSIS OF A VIRTUAL ARTILLERY UNIT MODEL FOR GAMING SCENARIOS

1. A model has been developed to manage the operations of a VAU in a gaming environment. This model addresses the execution of combat tasks, specifically targeting and destroying an objective with a set number of shells. It also considers the strategic movement of the artillery unit by changing firing positions to minimize the likelihood of being targeted by the opposing artillery unit. The system dynamics of “attacking artillery unit – target – opposing artillery unit” are examined in the action processes. The model accounts for the reduction in combat capability over time due to sudden failures, wear and tear during combat operations and destruction by the opposing side.

The model assumes all shots are effective, with a hit probability of each shot being more than 50%. It presupposes that the number of firing positions equals the number of shots needed to hit the target, and the minimum number of shots from each position is one. The position-changing model does not consider returning to previous positions. Movement from one position to another is simulated sequentially along various quality roads with different probabilities of being targeted by the opposing side.

2. A methodology has been developed for determining the state of task execution by the attacking artillery unit based on the proposed model. The concept of the current structure of task execution is introduced, 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. The method for determining the state of task execution can be categorized as solving Pareto-oriented tasks or dynamic programming problems. However, the number of input parameters and variable arguments allowed for obtaining all possible solutions through direct enumeration.

The calculation method of the model consists of a general algorithm, underpinned by specialized additional algorithms. The “Positions” algorithm determines the current number of shells used at each position. The “Change of Position" algorithm establishes the sequence of road numbers used when changing positions. The “Combat Capability” algorithm calculates the final combat capability of the artillery unit upon completing the task with the current structure. The “Time” algorithm calculates the total time required to complete the combat task with the current structure.

3. For the proposed “hide and shoot” tactic in artillery unit operations, future research should focus on finding the best solutions for possible groups of variable arguments. This should take into account the relative value of the attacking artillery unit and the target, as well as the losses incurred by the attacking side if the target is not destroyed. This approach will enhance the strategic depth of the game, allowing players to explore various outcomes based on different operational tactics and enemy engagements.

REFERENCES

1. Uludağlı, M. Ç. & Oğuz, K. "Non-player character decision-making in computer games". *Artif Intell Rev.* 2023; 56: 14159–14191, https://www.scopus.com/record/display.uri?eid=2-s2.0-85153938631&origin=resultslist. DOI: https://doi.org/10.1007/s10462-023-10491-7.

2. Studiawan, R., Hariadi, M. & Sumpeno, S. "Tactical Planning in Space Game using Goal-Oriented Action Planning". *Journal on Advanced Research in Electrical Engineering*. 2018; 2 (1): 5–11. DOI: https://doi.org/10.12962/j25796216.v2.i1.32.

3. Suyikno, D. A. & Setiawan, A. "Feasible NPC Hiding Behaviour using Goal Oriented Action Planning in case of Hide-and-Seek 3D Game Simulation". *2019 Fourth International Conference on Informatics and Computing (ICIC)*. Semarang: Indonesia. 2019. p. 1–6. DOI: https://doi.org/10.1109/ICIC47613.2019.8985962.

4. Singh, N. & Verbrugge, C. "Staying Hidden: An analysis of hiding strategies in a 2D Level with Occlusions". *Proceedings of the AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment*. 2021; 12 (1): 72–78. DOI: https://doi.org/10.1609/aiide.v12i1.12854.

5. Lu, T., Chen, K., Zhang, Y. & Deng, Q. "Research on dynamic evolution model and method of communication network based on real war game". *Entropy*. 2021; 23 (4): 487. DOI: https://doi.org/10.3390/e23040487.

6. Chen, H., Wang, L. & Wang, X. "A combat game model with inter-network confrontation and intra-network cooperation". *Chaos*. 2023; 33 (3): 033123. DOI: https://doi.org/10.1063/5.0137338.

7. Ding, Z., Chen, C., Cui, M., Bi, W., Chen, Y. & Li, F. "Dynamic game-based defensive primary frequency control system considering intelligent attackers". *Reliability Engineering & System Safety*. 2021; 216: 107966. DOI: https://doi.org/10.1016/j.ress.2021.107966.

8. Kang, B. G., Choi, S. H., Kwon, S. J., Lee, J. H. & Kim, T. G. "Simulation-Based Optimization on the System-of-Systems Model via Model Transformation and Genetic Algorithm: A Case Study of Network-Centric Warfare". *Complexity*. 2018; 4521672. DOI: https://doi.org/10.1155/2018/4521672.

9. Nohel, J., Stodola, P., Flasar, Z. & Rybanský. M. "Multiple maneuver model of cooperating ground combat troops". *The Journal of Defense Modeling and Simulation*. 2023; 20(4): 481–493, https://www.scopus.com/record/display.uri?eid=2-s2.0-85125142278&origin=resultslist. DOI: https://doi.org/10.1177/15485129221078939

10. Blaha, M., Šilinger, K. & Potužák, L. "Linear and Angular Issues in Perspective Artillery Fire Control System". *MATEC Web Conf.* 2018; 210: 02055. DOI: https://doi.org/10.1051/matecconf/201821002055.

11. Šilinger, K. & Blaha, M. "The New Automated Fire Control System for Artillery Units based on Interoperability and Standards". In *Proceedings of the 14th International Conference on Informatics in Control, Automation and Robotics.* 2017; 1: 332–337, https://www.scopus.com/record/display.uri?eid=2-s2.0-85029310208&origin=resultslist. DOI: https://doi.org/10.5220/0006468003320337.

12. Kim, D.-S., Bae, J. W., Park, S. B. & Kim, T. G. "Research of interoperation simulation between war game simulator and communication effect simulator using HLA/RTI". *Journal of the Korea Institute of Military Science and Technology. The Korea Institute of Military Science and Technology*. 2015; 18: 46–54. DOI: https://doi.org/10.9766/kimst.2015.18.1.046.

13 Kolesnyk, R. O. & Koba, A. B. "Software development for imitation of a war game by mathematical analysis" . *Connectivity*. 2020; 3: 57–59. DOI: https://doi.org/10.31673/2412-9070.2020.036170.

14. Ma, Y.-B., Kim, J.-K. & Lee, J.-S. "Modeling and simulation of ontology-based path finding in war-game simulation". *Journal of the Korea Society for Simulation*. 2012; 21 (1): 9–17. DOI: https://doi.org/10.9709/JKSS.2012.21.1.009.

15. Tucker, A. "Ender's Wargames: Drones, data and the simulation of war as weapon and tactic". In *Virtual Weaponry: The Militarized Internet in Hollywood War Films*. 2017. p. 145–185. DOI: https://doi.org/10.1007/978-3-319-60198-4_5.

16. Duong, D., & Bladon, C.M. "Interfacing and validating models of the US Army TRAC tactical war game". 2012. p.118–127. – Available from: https://www.taylorfrancis.com/chapters/edit/ 10.1201/b12317-16/interfacing-validating-models-us-army-trac-tactical-war-game. – [Accessed: Jul. 2022].

17. Amaguaña, F., Collaguazo, B., Tituaña, J. & Aguilar, W.G. "Simulation system based on augmented reality for optimization of training tactics on military operations". In *Augmented Reality, Virtual Reality, and*

Computer Graphics. 2018. p. 394–403, https://www.scopus.com/record/display.uri?eid=2-s2.0-85050368427&origin=resultslist. DOI: https://doi.org/10.1007/978-3-319-95270-3_33.

18. Bedi, P., Taneja, S.B., Satija, P., Jain, G., Pandey, A. & Aggarwal, A. "Bot development for military wargaming simulation". In: *Applications of Computing and Communication Technologies. ICACCT 2018. Communications in Computer and Information Science*. 2018. 899: 347–360, https://www.scopus.com/record/display.uri?eid=2-s2.0-85070896234&origin=resultslist. DOI: https://doi.org/10.1007/978-981-13-2035-4_30

19. Hoseok Moon. "A study on modeling of artillery probable errors for improving simulation logic of artillery damage assessment in war-game models". *Korean Journal of Military Art and Science*. 2020; 76 (1): 331–348. DOI: https://doi.org/10.31066/kjmas.2020.76.1.013.

20. Finlon, M. A. "Analysis of the field artillery battalion organization using a Markov *chain". Master's thesis. Naval Postgraduate School*. 1991. – Available from: https://core.ac.uk/download/pdf/36720787.pdf. – [Accessed: Dec. 2022].

21. Guzik, D. M. "Markov model for measuring artillery fire support effectiveness". *Master's thesis. Naval Postgraduate School*. 1988. – Available from: https://core.ac.uk/download/pdf/36716303.pdf. – [Accessed: Dec. 2022].

22. Shim, Y. "An analysis of shoot-and-scoot tactics (Master's thesis)". Naval Postgraduate School. 2017. – Available from: https://apps.dtic.mil/sti/pdfs/AD1046113.pdf. – [Accessed: Jul. 2022], https://www.scopus.com/record/display.uri?eid=2-s2.0-85052795343&origin=resultslist.

23. Boltenkov, V, Brunetkin, O, Maksymova, O, Kuzmenko, V, Gultsov, P, Demydenko, V. & Soloviova, O. "Devising a method for improving the efficiency of artillery shooting based on the Markov model". *Eastern-European Journal of Enterprise Technologies*. 2021; Vol 6 No. 3 (114): 6–7, https://www.scopus.com/record/display.uri?eid=2-s2.0-85123511164&origin=resultslist&sort=plf-f&src=s&sid=0d1a843d2a9f783a0cb05d4bd5a6f328&sot=b&sdt=b&s=TITLE-ABS-KEY%28Devising+a+method+for+improving+the+efficiency+of+artillery+shooting+based+on+the+Markov+model%29&sl=109&sessionSearchId=0d1a843d2a9f783a0cb05d4bd5a6f328#metrics.
DOI: https://doi.org/ 10.15587/1729-4061.2021.245854.

24. Dobrynin, E., Maksymov, M. & Boltenkov, V. "Development of a method for determining the wear of artillery barrels by acoustic fields of shots". *Eastern–European Journal of Enterprise Technologies*. 2020; 3 (5) (105): 6–18, https://www.scopus.com/record/display.uri?eid=2-s2.0-85092477400&origin=resultslist&sort=plf-f&src=s&sid=c3c3878d69bfef9f296f1058fe9e870c&sot=b&sdt=b&s=TITLE-ABS-KEY%28Development+of+a+method+for+determining+the+wear+of+artillery+barrels+by+acoustic+fields+of+shots%29&sl=112&sessionSearchId=c3c3878d69bfef9f296f1058fe9e870c.
DOI: https://doi.org/10.15587/1729-4061.2020.209847.

25. Maksimova, O. B., Davydov, V. O. & Babych, S. V. "Optimization of control of heat supply systems of urban districts". *Journal of Automation and Information Sciences*. 2016; 48 (4): 69–89. DOI: https://doi.org/10.1615/JAutomatInfScien.v48.i4.70

26. Maksimova, O. B., Davydov, V.O. & Babych S.V. "Control of heat supply system with structural changeable hardware". *International Scientific Technical Journal "Problems of Control and Informatics"*. 2014; 46 (6): 37–48. DOI: https://doi.org/10.1615/JAutomatInfScien.v46.i6.40.

27. Dobrynin, Ye. V., Boltenkov, V. O. & Maksymov M. V. "Information technology for automated assessment of the artillery barrels wear based on SVM classifier". *Applied Aspects of Information Technology*. 2020; 3 (3): 117–134. DOI: https://doi.org/10.15276/aait.03.2020.1.

28. Dobrynin, Y., Volkov, V. Maksymov, M. & Boltenkov, V. "The development of physical models for acoustic wave formation at the artillery shot and study of possibilities for separate registration of various types' waves". *Eastern–European Journal of Enterprise Technologies*. 2020; 4 (5) (106): 6–15, https://www.scopus.com/record/display.uri?eid=2-s2.0-85092473129&origin=resultslist&sort=plf-f&src=s&sid=1e3dffa592f537a8290ec25cc46a4bfc&sot=b&sdt=b&s=TITLE-ABS-KEY%28The+development+of+physical+models+for+acoustic+wave+formation+at+the+artillery+shot+and+study+of+possibilities+for+separate+registration+of+various+types%E2%80%99+waves%29&sl=176&sessionSearchId=1e3dffa592f537a8290ec25cc46a4bfc. DOI: https://doi.org/10.15587/1729-4061.2020.209847.

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Розробка та оптимізація імітаційних моделей та методів керування віртуальними артилерійськими установками в ігрових сценаріях

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АНОТАЦІЯ

У рамках розвитку сучасних відеоігор, особлива увага приділяється моделюванню артилерійських установок, які є ключовими елементами багатьох військових симуляцій. Це дослідження пропонує математичну модель для імітації дій віртуальної артилерійської установки, яка вирішує бойові завдання, враховуючи необхідність зміни вогневих позицій для підвищення ефективності і зменшення ймовірності виявлення ворожими силами. Модель розглядає всі постріли як ефективні та передбачає, що кількість вогневих позицій дорівнює кількості пострілів, з мінімальною кількістю одного пострілу з кожної позиції. У моделі також враховані різні якості доріг для переміщення між вогневими позиціями та концепція поточної структури виконання бойового завдання. Представлений метод пошуку рішення про стан виконання бойової задачі відноситься до Парето орієнтованих задач або задач динамічного програмування. Загальний алгоритм включає в себе спеціалізовані додаткові алгоритми, що дозволяють виконати бойове завдання з максимальною ефективністю. Результати дослідження демонструють, що тактика використання артилерійських установок у відеоіграх може значно відрізнятися в залежності від оборонної чи наступальної стратегії, і впливає на кількість використаних пострілів для знищення цілей. Таким чином, тактика "вистрілив і втік" може бути адаптована до різних ігрових сценаріїв як "сховався і вистрілив" або “hid and shot” у англійському перекладі.

Ключові слова: віртуальна артилерійська установка; ігрове моделювання; поточна структура; метод пошуку рішення; динамічне програмування; алгоритм; автоматизована система керування; відеоігри; військова симуляція

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