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DEVELOPMENT OF METHODS OF ARTILLERY CONTROL FOR SUPPRESSION OF AN ENEMY AMPHIBIOUS OPERATION IN VIDEO GAME SIMULATIONS

The paper describes the tactical methods of using artillery guns for counter-amphibious in deep and shallow water landscapes. The study's object is to model military game scenarios, in particular, the role of artillery forces in countering an amphibious operation of one or two divisions. One of the most problematic areas is combining continuous fire support and maneuvering to maintain artillery survivability and save ammunition with limited resources.

The study used mathematical models of combat resource utilization based on Markov chains, taking into account the probabilistic aspects of target destruction. Simulation models were also developed for various scenarios of countering amphibious assault ships, which allows for optimizing the number of shells and determining the most effective moments for opening fire.

Several approaches to firing have been developed and analyzed: methods of minimizing the number of shells, rapid neutralization of enemy targets, and mixed methods that allow finding a balance between minimizing resources and speed of response. Each method has its advantages depending on the combat situation: cost minimization methods are suitable for controlled scenarios. Instead, methods of rapid destruction are effective in high-risk situations but require more resources. A new mixed tactical method has been developed. This is because the proposed methods have several features, in particular, a large discrepancy in the predicted minefield, which also made it possible to assess the ability to hold the minefield of the fairway, which is important for protection against further attacks. This ensures the possibility of obtaining a high level of minefields on the fairway (up to 67.77 %). Compared to similar indicators, which ranged from 46.42 % to 67.77 %, but without specifying the method, this provided advantages in the form of the possibility of tactical maneuvering between the proposed methods, depending on the current state of resources and the proximity of enemy targets.

Keywords: *simulation modelling, Markov chains, game simulation, automated control in games, military simulation in video games.*

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1. Introduction

Developing effective strategies to protect the coast from maritime threats is an important topic for a game simulator that recreates modern military conflicts. Special attention is paid to dynamic resource management and adaptive solutions within defense scenarios. Classical approaches to managing military assets are often accompanied by significant resource expenditures and limited ability to respond to changing circumstances. This poses considerable challenges for developers seeking to maximize the effectiveness of artificial intelligence in relation to the player in amphibious assault scenarios.

One of the key aspects of the game is optimizing the use of ammunition and choosing the best moments to attack. In the context of limited resources, this requires the defense side to find innovative tactical approaches and make decisions based on complex algorithms. It is the use of integrated fire control systems that opens up new horizons for strategic planning and efficient use of combat resources.

Modern research in the field of artillery employment makes extensive use of mathematical and simulation modelling to improve the effectiveness of combat operations, focusing on resource optimization and adaptation to real combat conditions. In particular, the dynamic modelling method based on Markov discrete chains allows predicting the consumption of shells and artillery guns in countering the amphibious of a sea assault, which contributes to the effective planning of resource use [1, 2]. Integration of mathematical models, such as Kolmogorov's differential equations, into the teaching of military disciplines, helps students to better understand the applied aspects of mathematical theories [3]. An important place is occupied by models of missile and artillery units, which resolve the contradiction between the need to provide continuous fire support and the need to maneuver to increase the survivability of units in combat conditions. These models take into account the non-stationary Poisson flow and allow for achieving an optimal balance between staying in position and maneuvering [4]. Studies of theoretical and practical aspects of artillery fire emphasize the versatility of such models, the usefulness of which goes beyond artillery specialization [5]. In coastal environments, the EFSM model demonstrates that artillery is more effective in scenarios where enemy maneuverability is limited, in particular during amphibious operations [6].

The problems of accuracy of artillery munitions guidance remain relevant, and researchers propose the creation of high-precision munitions with combined guidance systems, which significantly improves the effectiveness of strikes [7]. The distribution of fire by region, implemented through special algorithms, proves its practical effectiveness in combat missions [8]. The analysis of amphibious operations in different hydrographic conditions allows to adapt tactics to the specific characteristics of the environment, which is important for the successful conduct of operations [9]. Considerable attention has been paid to the modelling of combat operations in the digital environment, where the use of Markov processes to simulate artillery operations increases the realism and accuracy of such simulations, which can be useful for military training and exercises [10]. The use of three-dimensional terrain models in troop management allows for improved planning and visualization of combat operations, providing a tactical advantage [11]. The MRSI (Multiple Rounds Simultaneous Impact) method, based on the Monte Carlo method, demonstrates its effectiveness in scenarios involving the defeat of moving targets, improving the overall accuracy of artillery strikes [12]. New approaches to fire correction allow for minimizing errors in the direction and range of fire, which optimizes ammunition consumption and the time to complete fire missions [13]. Finally, modelling the use of artillery units in defense operations using Markov processes offers approaches to ensuring a balance between fire support and maneuvering to increase their survivability [14]. The study of the effect of the temperature of powder gases in the gun barrel on the formation of free carbon contributes to the improvement of internal ballistics models, which increases the accuracy of artillery fire [15]. The development of methods for analytical solution of the Riccati equations provides a more accurate description of the parameters of combat objects and helps to optimize their use in combat conditions [16]. In addition, models of acoustic wave formation during an artillery shot open up opportunities to improve the accuracy of signal registration and monitoring of combat operations [17].

Thus, the analysis of current research shows that the main problem remains the contradiction between the requirement to provide continuous fire support, and the need for constant maneuvering to maintain the survivability of artillery units and save ammunition in conditions of limited resources. One of the key approaches to solving this problem is modelling according to the Markov process scheme, which allows to formulation reasonable recommendations for optimizing the functioning of artillery in modern combat conditions.

The aim of research is to develop tactical methods for the operation of artillery guns by artificial intelligence, which seeks to prevent the implementation of a counter-amphibious operation planned by the player in a resource-limited mode through a computer-integrated system for controlling the number of shells.

Problem statement:

– to consider and describe a mathematical model of the use of combat resources to counteract the landing of a sea amphibious force based on Markov chains;
– to develop a program for simulation modelling of various scenarios of countering an amphibious operation;
– to propose tactical methods of countering amphibious operations of two types;
– to analyze the application of the proposed methods.

2. Materials and Methods

2.1. Mathematical modelling of the calculation of the number of shots to defeat marine targets in amphibious operations

A mathematical model was considered that allows estimating the required number of shots of an artillery gun to effectively destroy various types of ships during an amphibious operation. The model is based on a probabilistic approach that takes into account the scattering of shells, geometric parameters of the target, as well as expert assessments of the conditions of combat use.

It is assumed that the scattering of shells occurs in accordance with the normal law of distribution of a random variable with a distribution density function (1), and the probability of hitting a ship is calculated using the formula for the probability of hitting a rectangle (2), the dimensions of which along the front and depth of the target are *2m* and *2l* [1]:

$$f(x)=\frac{\rho}{E\sqrt{\pi}}e^{-\frac{\rho^2}{E^2}(x-m)^2}, \qquad (1)$$

$$P((X,Y)\subset R)=\frac{1}{2}\left[\Phi^*\left(\frac{(x+l)}{V_b}\right)-\Phi^*\left(\frac{(x-l)}{V_b}\right)\right]\times$$
$$\times\left[\Phi^*\left(\frac{(z+m)}{V_d}\right)-\Phi^*\left(\frac{(z-m)}{V_d}\right)\right], \qquad (2)$$

where m is the center of scattering; $\rho\approx 0.477$; E is the probable deviation; x and z are the distance of the center of scattering of projectiles from the center of the target; V_b and V_d are the lateral probable deviation and the probable deviation in range; $\Phi^*(x)$ is the Laplace function.

The probability of hitting each type of ship at least k times is determined by the Bernoulli formula.

The model used expert estimates to analyze the degree of damage to each type of ship and to analyze the transition of "damage" states [2–5] that satisfy the Markov properties [1, 10]. The transition graph of the Markov chain of the transition probability matrix (3) is shown in Fig. 1. It is also assumed that highly mobile artillery systems are involved in the operation, which change their position after each series of shots to avoid the risk of return fire.

$$S=\begin{bmatrix} 1 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ p_1 & 0 & q_1 & 0 & \cdots & 0 & 0 & 0 \\ p_2 & 0 & 0 & q_2 & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ p_{12} & 0 & 0 & 0 & \cdots & q_{12} & 0 & 0 \end{bmatrix}. \qquad (3)$$

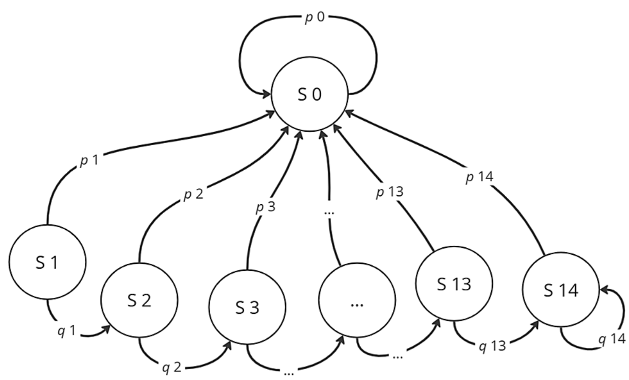

Fig. 1. Markov chain transition graph for the conditions and characteristics of an amphibious ship, where p_i is the probability of "destruction" of the ship, $q_i=1-p_i$

The results of calculations of the probability of a hit and the required number of shots create the basis for furthermore detailed analysis, which is carried out using simulation modelling of the process of destroying the ship.

2.2. Simulation modelling of defeating maritime targets in amphibious operations

The required amount of time, series of shots and shells to destroy each type of ship was calculated. The model takes into account not only the technical characteristics of guns and ships, but also tactical parameters such as the speed of the ship's approach, firing intervals, and firing conditions [6] (the program was developed using the Scilab package).

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First of all, the *main.sci* function was developed, which performs basic calculations, including determining the speed of the ship's approach to the shore and the number of shells that can be fired within a certain period of time.

```
function ship=main(txt, shooters, x, ships, prompt)
 ship = struct();
 ship.data = load_data(txt, x, ships);
 data = ship.data; ship.ratefire = data.ratefire; // entering information about the control object
 ratefire = ship.ratefire; ship.timestep = data.time_mins + 2; // rate of fire per minute
 timestep = ship.timestep; // time step - 4 minutes
 ship.oneset = ship.ratefire * 2; // shells per ship.timestep minutes
 ship.speed4mins = ship.data.speed / 60 * 4; // distance in 4 minutes
 //Calculations
 ship.segments = process_segments(data); segments = ship.segments; // Model intervals (ellipses)
 ship.V = V_load(segments, data); V = ship.V; // Intervals of the density ellipse
 ship.F = norm_dist_load(V, data); F = ship.F; // Probability of hit
 ship.M = hit_prob_matrix(txt, data, V, F); M = ship.M; // damage probability matrix
 ship.Prob_k = prob_var_load(M, data, shooters, ships, ratefire);
 Prob_k = ship.Prob_k; // probability of damage
 ship.d_forMark = add_data_forMark(data.time_mins, data, segments, timestep);
 d_forMark = ship.d_forMark; // additional data in the form of time and distance for the state matrix
 if txt == 'ДКа' then // DKa ship type in Cyrillic
 shooters = ships;
 [ship.mct, ship.mcsm] = DKa_func(d_forMark.T, d_forMark.Sm, ships, shooters, ship.oneset);
 mprintf(' Швидкість наближення ДКа до берега %f км за 4 хв\n', ship.speed4mins); // in Ukrainian: "The speed of approaching the ship to the shore %f km per 4 min\n"
 else
 mcsm = d_forMark.Sm($); ship.mcsm = mcsm; mct = d_forMark.T($);
 ship.mct = mct; // last elements of the array
 ship.Mark_chain = func_Mark(d_forMark.Sm, d_forMark.T, data, M, Prob_k, prompt);
 Mark_chain = ship.Mark_chain; // state matrixes
 ind = Mark_chain.index; // index if prob >= 95 % to display the approximate minute of destruction and km from the shore at that moment
 sm_shore = Mark_chain.Sm(Mark_chain.time_interval); ship.sm_shore = sm_shore;
 ship.Mark_chain.index = Mark_chain.index; ship.newmct = d_forMark.T(Mark_chain.indT);
 ship.newmcsm = d_forMark.Sm(Mark_chain.indT);
 end
endfunction
```

Using the main calculation function, *combinations.sci* was developed to search through all possible combinations of initial firing times for different types of ships to determine the optimal moments to start firing in order to minimize the number of shells required and increase the probability of hitting.

```
exec('task.sci'); clc;
DK1171_Mtx = combo(DK1171); DK775_Mtx = combo(DK775);
TSCH_Mtx = combo(TSCH);
DKa = main('ДКа', 182, 152, 1, 2); // DKa ship type in Cyrillic
function ship_Mtx=combo(ship)
 txtname = ship.data.name; n = ship.mct - 4; progression_array = 2:4:n;
 size_of_array = length(progression_array); ship_Mtx = zeros(size_of_array, 11);
 for i = 2:4:n
 temp_ship = main(txtname, 182, 152, 1, i);
 clc;
 ship_Mtx(i, 1) = 2; // time of entry into the water area
 ship_Mtx(i, 2) = 26.5; // distance of entry into the water area
 ship_Mtx(i, 3) = ship.mct; // time of the probable start of the landing
 ship_Mtx(i, 4) = ship.mcsm; // distance of the probable start of the landing
 ship_Mtx(i, 5) = i; // time of the beginning of the shelling
 ship_Mtx(i, 6) = temp_ship.newmct; // time of the end of the shelling
 ship_Mtx(i, 7) = temp_ship.sm_shore; // distance of the start of the shelling
 ship_Mtx(i, 8) = temp_ship.newmcsm; // distance of the end of the shelling
 ship_Mtx(i, 9) = temp_ship.Mark_chain.index; // a series of shots is required
 ship_Mtx(i, 10) = 180 * temp_ship.Mark_chain.index; // number of shells needed to destroy
 ship_Mtx(i, 11) = (ship.mct - temp_ship.newmct) / 4; // series of shots left before the landing
 end
 ship_Mtx = ship_Mtx(find(~all(ship_Mtx == 0, 2)), :);
endfunction
```

After implementing the simulation, it is possible to obtain combinations of parameters such as the start time of the attack, the duration of the attack, the distance from the shore (both the start and end points of the attack), as well as the amount of series of shots and the total number of required shells, which are presented in Tables 1–3 and Fig. 2.

Table 1

Modelling results for a ship of the MTSh type (minesweeper "МТЩ")

Start shelling time, min	Start shelling time, min	Distance from the coast (starting point of the shelling), km	Distance from the coast (endpoint of the shelling), km	Required series of shots to destroy	Number of shells required for destruction (18 guns, 10 shots per time step of 4 minutes)	Series of shots before the potential landing of the amphibious
1	2	3	4	5	6	7
2.00	26.00	26.50	19.84	6.00	1080.00	17.00
6.00	26.00	26.50	19.84	5.00	900.00	17.00
10.00	30.00	26.50	18.73	5.00	900.00	16.00
14.00	30.00	26.50	18.73	4.00	720.00	16.00
18.00	30.00	26.50	18.73	3.00	540.00	16.00
22.00	30.00	26.50	18.73	2.00	360.00	16.00
26.00	34.00	25.39	17.62	2.00	360.00	15.00

Continuation of Table 1

1	2	3	4	5	6	7
30.00	38.00	25.39	16.51	2.00	360.00	14.00
34.00	42.00	25.39	15.40	2.00	360.00	13.00
38.00	46.00	25.39	14.29	2.00	360.00	12.00
42.00	46.00	25.39	14.29	1.00	180.00	12.00
46.00	50.00	24.28	13.18	1.00	180.00	11.00
50.00	54.00	24.28	12.07	1.00	180.00	10.00
54.00	58.00	23.17	10.96	1.00	180.00	9.00
58.00	62.00	23.17	9.85	1.00	180.00	8.00
62.00	66.00	23.17	8.74	1.00	180.00	7.00
66.00	70.00	22.06	7.63	1.00	180.00	6.00
70.00	74.00	22.06	6.52	1.00	180.00	5.00
74.00	78.00	20.95	5.41	1.00	180.00	4.00
78.00	82.00	19.84	4.30	1.00	180.00	3.00
82.00	86.00	19.84	3.19	1.00	180.00	2.00
86.00	90.00	18.73	2.08	1.00	180.00	1.00
90.00	94.00	18.73	0.97	1.00	180.00	0.00

Table 2

Modelling results for the ship type DK1171 (amphibious assault ship "ДК1171")

Start shelling time, min	Start shelling time, min	Distance from the coast (starting point of the shelling), km	Distance from the coast (endpoint of the shelling), km	Required series of shots to destroy	Number of shells required for destruction (18 guns, 10 shots per time step of 4 minutes)	Series of shots before the potential landing of the amphibious
2.00	30.00	26.50	12.69	7.00	1260.00	6.00
6.00	30.00	26.50	12.69	6.00	1080.00	6.00
10.00	30.00	26.50	12.69	5.00	900.00	6.00
14.00	30.00	24.53	12.69	4.00	720.00	6.00
18.00	30.00	24.53	12.69	3.00	540.00	6.00
22.00	30.00	24.53	12.69	2.00	360.00	6.00
26.00	30.00	22.55	12.69	1.00	180.00	6.00
30.00	34.00	20.58	10.71	1.00	180.00	5.00
34.00	38.00	20.58	8.74	1.00	180.00	4.00
38.00	42.00	18.61	6.77	1.00	180.00	3.00
42.00	46.00	16.63	4.79	1.00	180.00	2.00
46.00	50.00	14.66	2.82	1.00	180.00	1.00
50.00	54.00	12.69	0.85	1.00	180.00	0.00

Table 3

Modelling results for the ship type DK775 (amphibious assault ship "ДК775")

Start shelling time, min	Start shelling time, min	Distance from the coast (starting point of the shelling), km	Distance from the coast (endpoint of the shelling), km	Required series of shots to destroy	Number of shells required for destruction (18 guns, 10 shots per time step of 4 minutes)	Series of shots before the potential landing of the amphibious
2.00	26.00	26.50	13.54	6.00	1080.00	6.00
6.00	26.00	26.50	13.54	5.00	900.00	6.00
10.00	26.00	26.50	13.54	4.00	720.00	6.00
14.00	26.00	24.34	13.54	3.00	540.00	6.00
18.00	26.00	24.34	13.54	2.00	360.00	6.00
22.00	26.00	24.34	13.54	1.00	180.00	6.00
26.00	30.00	22.18	11.38	1.00	180.00	5.00
30.00	34.00	20.02	9.22	1.00	180.00	4.00
34.00	38.00	20.02	7.06	1.00	180.00	3.00
38.00	42.00	15.70	4.90	1.00	180.00	2.00
42.00	46.00	13.54	2.74	1.00	180.00	1.00
46.00	50.00	11.38	0.58	1.00	180.00	0.00

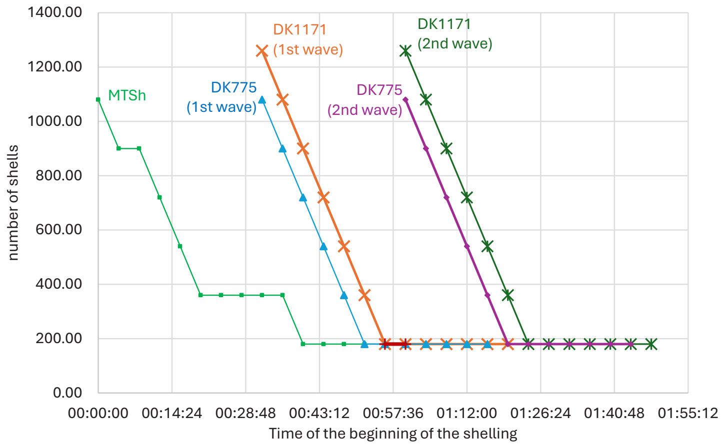

Fig. 2. The required number of shells to destroy each type of ship

The modelling allows to formulate the need to choose tactics for destroying targets, taking into account different conditions for opening fire in order to plan artillery support in more detail and determine the optimal moments for starting the fire, depending on the characteristics of the ships approaching the shore.

2.3. Tactical methods of artillery gun operation

Based on the data from Tables 1–3 and Fig. 2, it was found that for each type of ship, there is a certain point of approach or distance to the shore, after which the situation changes. Starting from a certain point of approaching the target, the division has the highest potential for destruction [5], and therefore, for each type of ship, only one series of shots from one division consisting of 18 guns is sufficient.

Also, due to the smaller size and higher speed of the LCS compared to other ships, they will be fired exclusively with the "Full (direct fire)" charge type.

Two scenarios of an amphibious operation are considered [9]:

A) Amphibious operation in the area of deep-water fairway.

The operation consists of 26 ships divided into 2 waves of attack, which operate according to the following schedule:

– MTSh, 4 ships: from 00:00 to 01:32;
– KVP (fire support ships "КВП"), 8 ships: from 00:28 to 02:56.

1st wave:

– DK1171, 1 ship: from 00:32 to 01:24;
– DK775, 3 ships: from 00:32 to 01:20;
– Dka, (small amphibious assault boat "Дка"), 6 boats: from 00:40 to 01:04.

2nd wave:

– DK1171, 1 ship: from01:00 to 01:52;
– DK775, 3 ships: from 01:00 to 01:48.

B) Amphibious operation in the area of shallow water.

The operation consists of 10 ships and 30 boats divided into 2 waves of attack, which operate according to the following schedule:

– KVP, 8 ships: from 00:00 to 02:28.

1st wave:

– DK775, 2 ships: from 00:04 to 00:52;
– Dka, 15 boats: from 00:12 to 00:36.

2nd wave:

– DK775, 2 ships: from 00:32 to 01:20;
– Dka, 15 boats: from 00:40 to 01:04.

For Scenario A, 8 tactical methods of using combat resources to counter the amphibious landing were proposed:

For one division of 18 guns:

– *min_shells18* – the method of minimizing shells, provided that each ship is fired upon when it is close to the distance of highly probable rapid destruction [7, 8];
– *quick_dmg18* – a method of minimizing the time spent by each ship in the mined fairway area, characterized by the immediate start of firing on each ship when it reaches the distance of the target range;
– *risk18* – a method of destroying each ship at the last moment before approaching the 0.5 km isobath zone.

For two divisions of 36 guns:

– *min_shells36* – a method of minimizing shells, provided that each ship is fired upon when it is close to the distance of highly probable rapid destruction;
– *quick_dmg36* – a method of minimizing the time spent by each ship in the mined fairway area, characterized by the immediate start of firing on each ship when it reaches the distance of the target range;
– *risk36* – a method of destroying each ship at the last moment before approaching the 0.5 km isobath zone;
– *mixed36* – a mixed method, in which the first to be destroyed is the MTSh in order to leave most of the fairway mined, and the subsequent destruction follows the *min_shells36* method;
– *mixed_risk36* – a mixed method, in which the first to be destroyed is the MTSh in order to leave most of the fairway mined, and further destruction follows the *min_risk36* method.

For scenario B, since mining is not possible due to the landscape of the fairway, the methods *min_shells18, quick_dmg18, risk18, min_shells36, quick_dmg36, risk36* were used.

3. Results and Discussion

The results of modelling the use of various tactical methods for counter-amphibious operations were analyzed. The results of the simulation are presented in Tables 4, 5, which compare the effectiveness of different methods of using artillery resources for scenarios A and B.

Table 4

Modelling the application of tactical methods for the scenario of amphibious operation A

Tactical method	min_shells 18	quick_dmg 18	risk18	min_shells 36	quick_dmg 36	mixed 36	risk 36	mixed_risk 36
End of the operation	01:36:00	01:36:00	01:56:00	01:28:00	01:28:00	01:28:00	01:56:00	01:56:00
Amount of shells consumed	2340.00	4320	2340	2340	7740	4500	2340	4500
Partially mined upon completion	8.54 %	21.35 %	8.54 %	4.27 %	8.54 %	8.54 %	4.38 %	8.54 %
Fully mined upon completion	46.42 %	54.96 %	3.73 %	50.69 %	67.77 %	67.77 %	3.62 %	67.77 %

Table 5

Modeling the use of tactical methods for the scenario of an airborne operation B

Tactical method	min_shells18		quick_dmg18		risk18		min_shells36		quick_dmg36		risk36	
Ship type	Dk775	Dka	DK775	Dka	DK775	Dka	DK775	Dka	DK775	Dka	DK775	Dka
The end of the operation	01:08:00		01:08:00		01:24:00		01:08:00		01:08:00		01:24:00	
Ships reached the shore	0	6	0	6	0	6	0	0	0	0	0	0
Shells consumed	1440.00		2880.00		1440.00		1800.00		4860.00		1800.00	

The *quick_dmg18* and *quick_dmg36* methods demonstrate the shortest completion time of 01:28:00, which allows for quick neutralization of landing craft but requires more shells compared to other methods. Shell minimization methods, such as *min_shells18* and *min_shells36*, can significantly reduce the number of shells used, but this can lead to an increase in the time spent by ships in the minefield, which increases the risk of some ships successfully reaching the coastline.

Table 4 also shows the percentage of the fairway that remained mined after the operation. The *mixed36* and *mixed_risk36* methods provide the highest level of mined areas – up to 67.77 %, which contributes to better protection against future attacks, but also requires significant resources and time.

For Scenario B (shallow water), the results of using each method to destroy landing craft and amphibious ships: *min_shells18* and *min_shells36* methods contributed to the destruction of all landing craft, not allowing any to reach the shore, but this was not possible for DK-type boats, which indicates the limitations of these methods in dealing with faster and more maneuverable targets.

It can be concluded that in Scenario B, minimizing the number of projectiles is possible without significant damage to the effectiveness of the operation against DK775 ships, but not for the fast-response DK boats.

Each of these methods has its advantages and disadvantages depending on the chosen targets, available resources, and the conditions of operations.

Fig. 3–5 show the number of guns that were not used during the counter-amphibious operation A at different points in time for each of the tactical methods considered. This makes it possible to assess the effectiveness of artillery use at each moment of the operation, as well as to identify possible reserves for increasing the intensity of the attack.

Fig. 6 shows the percentage of the fairway that remained mined or partially mined at the end of the operation. The data demonstrates that methods that minimize time or resources are often accompanied by insufficient levels of mined areas, which can create vulnerabilities for further attacks.

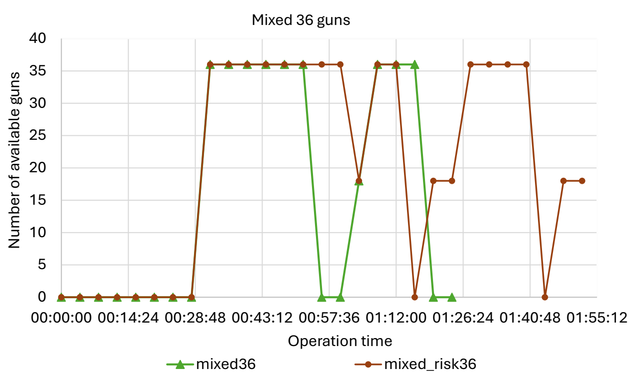

Fig. 3. Number of unused guns during counter-amphibious operation A for mixed tactics for 36 guns

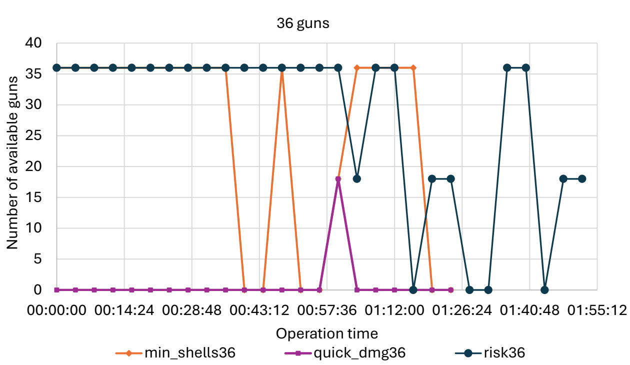

Fig. 4. Number of unused guns during counter-amphibious operation A for other tactics for 36 guns

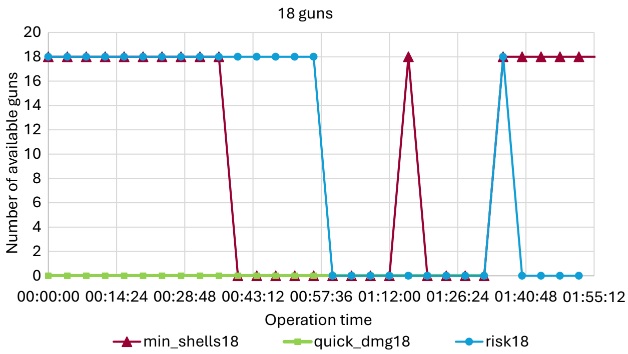

Fig. 5. Number of unused guns during counter-amphibious operation A for 18 guns

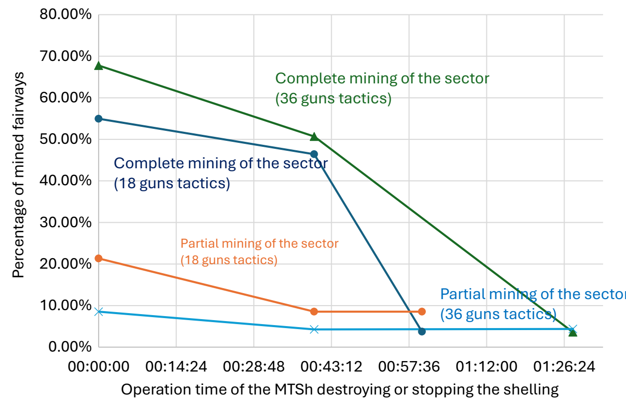

Fig. 6. Percentage of mined or partially mined fairway after the end of counter-amphibious operation A

As noted earlier, Scenario B does not include fairway mining, and it is also observed that under certain conditions, it is impossible to avoid landing craft reaching 0.5 km of the isobath before being completely destroyed. Fig. 7–9 provide additional information on the number of guns that were not used during the various stages of Operation B, which emphasizes the potential reserves and the possibility of increasing the effectiveness of the attack.

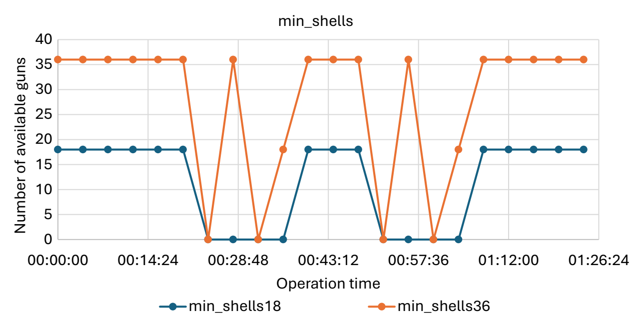

Fig. 7. Number of unused guns during counter-amphibious operation B for min_shells tactics

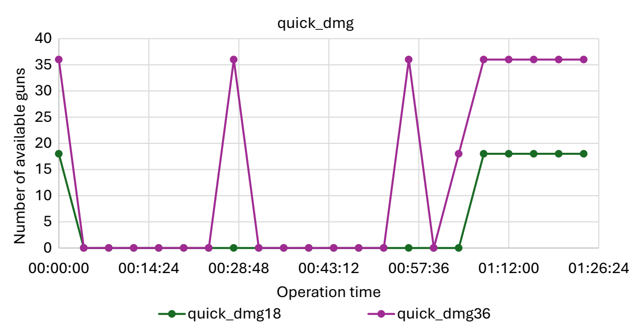

Fig. 8. Number of unused guns during counter-amphibious operation B for quick_dmg tactics

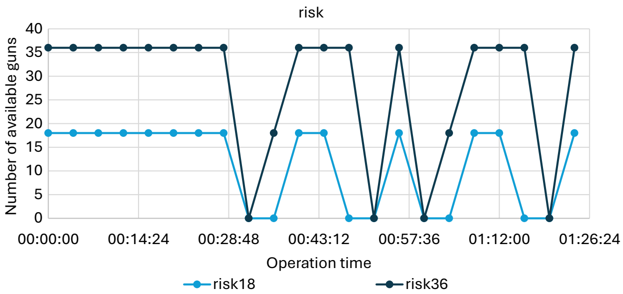

Fig. 9. Number of unused guns during counter-amphibious operation B for risk tactics

Fig. 10 shows the number of ships that remained in the fairway zone from the beginning to the end of the counter-amphibious operation. This is an important indicator for assessing the effectiveness of tactical methods, as it allows to visually assess which tactics lead to the fastest and most effective destruction of the enemy, and which ships will reach the 0.5 km isobath.

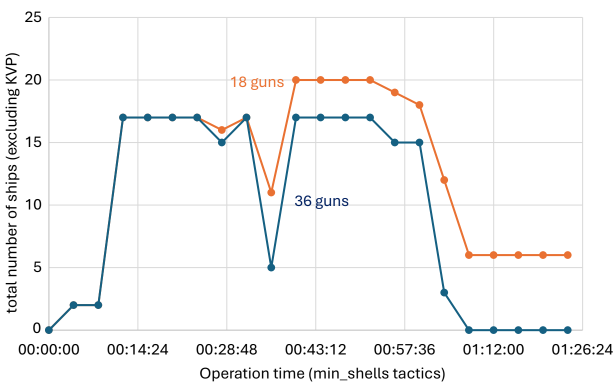

Fig. 10. The number of ships in the fairway area from the beginning to the end of the counter-amphibious operation

The analysis showed that to ensure maximum effectiveness of a counter-amphibious operation, it is necessary to take into account not only the number of resources used but also the speed of response to changing combat conditions. Methods that minimize the number of shells are appropriate in a more controlled situation, while rapid neutralization of the enemy requires immediate and more intensive action, even if it requires more resources.

Practical relevance. The use of mixed strategies has shown the prospect of achieving a high level of efficiency in the game, ensuring a balance between saving resources and accomplishing tasks (it becomes possible to ensure a high level of fairway mined – up to 67.77 %). Such approaches make it possible to create more intense game scenarios that require players to plan and make decisions quickly.

Research limitations include its focus on game simulations, which may not take into account all factors of real combat conditions, such as unpredictable changes, modern technologies, adaptive tactics, and a dramatic change in the theatre of operations landscape. The developed models are based on theoretical assumptions and may be less effective when weather conditions change or other combat weapons are used. For practical implementation, it is necessary to adapt the results to real conditions, conduct additional empirical research, take into account the losses of defense forces, and develop more accurate models to take into account dynamically changing circumstances.

The impact of martial law conditions. The research was conducted in the context of limited access to physical resources, which made it impossible to conduct empirical tests and focused on mathematical modelling and simulations. In addition, priorities in the military sphere influenced the shift in emphasis in the research, focusing it on solving urgent defense problems. In addition, resource constraints caused directly by martial law contributed to the focus on efficiency and resource optimization in the virtual environment, which is reflected in the research results.

Prospects for further research. To improve the gaming experience should focus on implementing more accurate models that take into account the complexity of dynamic conditions, probable losses among the defending side's firepower, as well as new tactical methods of firing, including support ships, or assessing the feasibility of maintaining a minefield.

4. Conclusions

The results reflect the importance of an integrated approach to resource management within tactical game scenarios. Particular attention was paid to cost optimization and adaptation to dynamically changing conditions, which is important for creating a realistic gaming experience. The use of an integrated resource management system made it possible to evaluate the effectiveness of various target destruction strategies in coastal defense scenarios.

The analysis shows that the tactics of minimizing the use of ammunition can significantly save resources, but this is often accompanied by an increase in the risk of successful completion of tasks by the enemy. At the same time, rapid destruction techniques provide rapid neutralization of targets, although they require significant resources, which can be a challenge in scenarios with severe constraints.

The simulations also showed that the cost minimization strategy is effective against large and less maneuverable targets, while fast and agile units require more adaptive approaches. This underscores the importance of flexibility in the choice of tactics, taking into account the characteristics of the opposing sides and the specific conditions.

In general, the study confirmed the need for a dynamic and adaptive approach to the development of tactics and strategies in war-based simulations. This allows for the creation of realistic game situations that not only test the player's tactical skills but also provide a deep gaming experience.

Conflict of interest

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

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The study was conducted without financial support.

Data availability

Data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in the creation of the presented work.

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