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Missile Strike Simulation in a Video Game Engine

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Abstract

In the field of modern computer gaming (especially within the genre of war-game strategies, realistic first-person shooters and other warfare games) the complexity of virtual naval warfare mechanics and strategies significantly increases. There is a growing demand for advanced simulation tools to provide more immersive experience and more complex gameplay for all players. The goal of this research is to create a model and tool that can accurately predict the impact of anti-ship missiles on ships engaged in different game scenarios, considering a wide range of battle conditions. By encompassing a broad array of missile types, landing strategies, ship classes, aircraft types, reconnaissance options, electronic warfare technologies and various anti-air and missile defense systems, the simulation includes both offensive and defensive maneuvers to make sure that anti-ship missiles are important within the game scenarios. Firstly, the research focuses on enhancing prediction models for calculating the damage inflicted by missile strikes on opposing naval forces. Secondly, it seeks to refine algorithms for determining the required number of missiles to prevent rival player advances, thereby maximizing operational efficiency and effectiveness in defensive missions.

Keywords: computer game; anti-ship missiles; missile guidance simulation; naval landing; simulation framework.

1. Introduction

In the evolving landscape of modern computer gaming, there is a rising demand for realistic and immersive game experiences. There are many popular genres which offer realistic and immersive experiences across a wide range of activities, such as piloting different types of vehicles, sport cars, planes, ships, and all kinds of combat vehicles.

Among simulation types of games, the war-game genre contains simulation of all types of military systems, vehicles, equipment. War-games allow players to replay and experience different historical or hypothetical conflicts and allow players to put themselves in any role, vehicle operators, commanders, special troops, etc.

Our examination will focus on naval operations, specifically on the interactions among artillery, anti-ship missiles, and naval forces in the context of naval assaults. Video game engines necessitate the development of an efficient model and methodology for assessing the damage effectiveness of anti-ship missiles. This includes the need for an automated system capable of calculating missile guidance accuracy, hit probability, and the likelihood of missiles evading interception by enemy air forces. Additionally, it involves evaluating the strategic deployment of forces for mission execution. Such systems are crucial for increasing the effectiveness of defense missions and optimizing ammunition usage and allowing players to make informed decisions.

Our game development framework is designed to simulate a wide variety of combat scenarios, each differing in strategic elements. Game engine database contains a comprehensive catalog of missile types, each with distinct capabilities and stats [1]. We also test different launcher configurations to see how their placement impacts battle

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outcomes within the game. Game engine database also includes a range of naval ship types, each classified by their role and formation tactics. With our model, we can assess how different ship formations are effective in different scenarios. Additionally, the game engine will have the range of an anti-air systems and fighter jets models, evaluating their effectiveness in countering missile attacks. This approach allows us to accurately calculate the impact of anti-ship missiles across various combat scenarios, providing a detailed and immersive gaming experience for naval combat operations [2].

In the context of video game simulation, in a strategy game setting, the player tasked with defending against rival naval operation must accurately predict the outcome of a defensive missile strikes. The process relies on an in-depth analysis of several key factors [3], [4], including evaluating the strength, strategy, and tactics of the rival player forces, assessing the defending player resources, strengths and possible setups, and considering the current game scenario environment settings, such as weather conditions, terrain advantages or disadvantages, and how these could influence both the attacking and defending players tactical options [5]. The goal for defending player is to optimize resource use to ensure that strategy is effective and sustainable over the course of the scenario. Simulation-based strategy games require players to plan and react dynamically to the changing tactics of their opponents. The simulation's accuracy plays an important role in ensuring a realistic and challenging experience, encouraging players to find innovative strategies and decisions to achieve victory.

While developing a video game that simulates combat operations, we can use data from real-world global conflicts and literature to establish realistic baseline parameters for all components within the game's simulation model [6], [7]. This process involves defining the effective range for missiles, impact power, and assessing the maneuverability, durability, and anti-aircraft capabilities of all ship types featured in the game. Also, it will include an evaluation of electronic warfare (EW) systems. Establishing these baseline values is essential for ensuring that the game accurately reflects the operational capabilities and limitations of every component, providing players with a detailed visualization of tactical and strategic interactions in a simulated combat environment.

2. Literature sources analysis

By examining various literature sources to understand the technical capabilities and effectiveness of rocket missiles, we can build a foundation for our study. This approach allows us to use the analysis of current models and methods as a benchmark and a baseline for our research [8], [9].

The literature presents an advanced guidance approach that enables multiple anti-ship missiles to coordinate their attack on naval targets more effectively. This technique improves their chances of breaching naval defenses by ensuring the missiles arrive at their targets simultaneously [2], [7]. The strategy involves a refined version of the proportional navigation guidance system, optimized to correct timing disparities through adjustments for biases, ensuring a same moment of impact. One of its key advantages is its flexibility in network requirements, allowing for efficient operation under both stable and changing communication conditions among the missiles. Simulation tests of this guidance method under a variety of conditions – including differences in missile starting points and speeds, changing communication network, and environmental factors like wind – confirm the missiles using presented guidance law can effectively navigate the complex and unpredictable combat scenarios.

Literature sources provide mathematical models to represent a combatant ship under both undamaged and damaged conditions. It employs an Estimation-Before-Modeling strategy, which first estimates state variables and parameters individually before analyzing the patterns of hydrodynamic forces [10], [11]. The study compares the ship's behavior in intact and damaged states and examines how damage impacts the ship's ability to maneuver. This comparison is supported by simulation results. The findings confirm how a ship's maneuvering capabilities are affected when it is damaged and offer a better understanding of the ship's operational behavior after sustaining damage.

We will use literature sources to define baseline parameters for all components inside the model, such as ships characteristics, missiles range and damage capabilities, anti-air systems and aircraft stats [12] – [14].

The literature introduces two innovative guidance strategies grounded in differential game theory, designed from an attacker standpoint within a scenario that includes an attacker, a defender, and a target. These strategies are crafted to allow the attacker to dodge the defender and keep a safe distance from the target, all without requiring knowledge of the target's or defender's control actions. The effectiveness of these guidance laws varies depending on initial conditions and has been proven through numerical simulations [9]. Furthermore, the literature outlines a tactical approach for attackers to effectively strike targets that are protected in missile defense situations.

Based on strategies and tactics that are provided by literature and tactical guides, we can define basic interactions within our model. We can define several basic scenarios for our game, separated by phases:

- Naval Transportation and Landing Operations: ships are primarily responsible for carrying naval personnel and military equipment across the sea. They are designed to perform landings on coastlines without prior preparation and in various weather conditions, which is crucial for the effective deployment of assault forces in most game scenarios.
- Reloading and Unloading of Landing Forces: This essential operation includes transferring landing troops from support vessels and larger landing crafts. The process involves efficient unloading both personnel and equipment into coastal areas or aquatic sites designated for landing operations within a game.
- Fire Support During Operation: As landing vessels get closer to their target landing zones, they are prepared to carry out attacks against rival player forces. They achieve this by using their onboard weapons to suppress and eliminate defending players' military assets and secure landing environment for the assault troops to land.
- Logistical Support: Beyond their combat duties, landing ships also play a crucial role in supplying vital resources to troops on the ground. Also, they undertake the important mission of evacuating injured personnel from the battlefield.

The defending player has the option to launch attacks during any of these phases. It is crucial to decide when to strike based on available resources, the current situation on the battlefield, and intelligence from other sources, to determine the most effective phase for launching an attack.

3. Objectives and tasks of the research

Basic gameplay scenario involves two players. The first one is an attacking player, who must escort the landing ships squadron to the opposing player territory to carry out the landing operations. The attacking player forces include the landing ships, defense and support ships, reconnaissance systems, EW systems and interceptor fighters. Defending player forces mostly consist of missile launchers.

The primary objective of the defending player is to destroy as many of the opponent's landing ships as possible with anti-ship missiles and stop the landing operation. It is essential for the defense to respond to any possible threats from the attacking player with the highest efficiency, which involves ensuring that all necessary equipment and personnel are ready and strategically placed to carry out their tasks effectively.

The first objective of the research is to define and optimize the model to calculate possible damage from a missile strike to rival player naval landing ships, considering all the parameters listed above.

The second objective of the research is to identify a method for finding an optimal number of missiles required to prevent opposing player naval landing operation, which will give useful tools for players and artificial intelligence (AI) to make informed decisions in different game scenarios.

4. Model and methods

The model is based around the main task of using anti-ship missiles against landing ships and finding the optimal way of missiles application in common game scenarios.

The allocation of defending player forces is optimized for the specific assigned task, which includes criteria for effectively accomplishing the mission. To decide on the exact setup of these forces, the player must evaluate the tactical abilities of missile carriers, their armaments, and the current tactical situation [12], [15]. This involves determining the optimal ratio of strike forces, how these forces could be grouped for simultaneous launches, and the order of these launches. Additionally, the distribution of missile launchers is influenced by the setup of defensive ships since their combat effectiveness directly impacts the success of the mission. It's also essential to explore different configurations of defensive forces to understand how their number and quality affect the mission's outcome. In the base scenario, the increase in the composition of the defending ships in attacking player naval squadron leads to an increase in the number of missile carriers.

The determination of the necessary number of anti-ship missile carriers and their equipment is established through detailed analysis. To help players make a decision in evaluating the outcomes of these analyses, it is essential to present the results in a manner that clearly illustrates how the effectiveness of combat missions varies under different scenarios. This necessitates performing comprehensive calculations and drawing conclusions regarding various potential configurations of friendly forces, enemy forces in the current game scenario. After receiving a mission objective, players can use previously conducted calculations and, if necessary, update them to suit the given situation.

To make an estimate for a success rate of a missile strike, we can separate calculations for different steps:

- Calculate the number of missiles that were intercepted by opposing fighter jets.
- Calculate the number of missiles that were destroyed by anti-air systems of rival player ships.
- Calculate the probability for a missile to aim at the landing ships or defense and support ships.
- Calculate the probability of destroying targeted ship with one hit, within one launch.

The probability of destroying a ship depends on a several factors [8], [16]:

- Opposing player anti-air capabilities.
- Class of the ship and its specifications.
- The number of successful hits on a targeted ship.
- Damage capabilities of an anti-ship missile.
- Homing capabilities of active missiles.

To accurately calculate the number of missiles that will be intercepted by enemy fighter aircraft, we have to consider several key factors [17]: the quantity of missiles in the salvo, the total time required to launch these missiles, the number of opposing interceptors that are supporting rival naval operations, their technical specifications, and the type of assisting reconnaissance systems.

To calculate the probability [5] of the missiles to evade rival fighter jet of k type we can use this formula:

$$Q_{fak}^{(j)} = 1 - P_{\mu ak}(1 - e^{-\frac{m\mu_k}{n}}), \quad (1)$$

where $P_{\mu ak}$ is the probability for interceptor of k type to hit missile, which depends on capabilities of opposing player reconnaissance systems, m is a number of active interceptors; μ_k is the damage potential of a k type interceptor against the j type missile [18]; n is the total number of missiles fired in a single launch.

Interceptors of the same model operate in separate groups. When multiple groups of interceptors are active, we can calculate the probability of missiles evading all groups of enemy fighters using the following formula:

$$Q_{fat} = \prod_{k}^{Nf} Q_{fak}, \quad (2)$$

where N_f is a number of active interceptor groups supporting rival landing.

To calculate the remaining number of missiles that avoided the interceptors attack we will use formula:

$$\overline{n} = nQ_{fat}, \quad (3)$$

where n is the total number of missiles fired in a single launch.

The number of missiles that can avoid enemy ships anti-air systems depends on the opposing squadron structure, the total area they cover, the anti-air capabilities of each ship within the "core" and "defense" groups, and the total time required to launch all missiles [8], [14].

To calculate the total time needed to launch all prepared missiles [21], [27], we can use formula:

$$T_j = (n_j - 1)\tau_j, \quad (4)$$

where n_j is an amount of missiles launched from the j-th carrier; τ_j is the time interval between each launch.

The total time required for a launch can be calculated with the formula:

$$T_a = T_j \max(1 + k_s(N_p - 1)), \quad (5)$$

where $T_j max$ is maximum value of T_j between all launchers; N_p is the total number of carriers which are active during missile attack; k_s = 0.2 is a statistical coefficient.

To find the number of missiles that will evade the enemy ships' anti-air means, we must assess and assign coefficients which define the anti-air capabilities for each type of opposing ship that are present in the game engine [18].

To calculate the total potential of anti-air means of opposing ships inside core and defense groups, we will use a formula:

$$\mu_{aa}^{c} = \sum_{k=1}^{N_c} \mu_{aak}^{c}, \tag{6}$$

$$\mu_{aa}^{d} = \sum_{k=1}^{N_d} \mu_{aak}^{d}, \tag{7}$$

where N_c and N_d are the number of ships inside the core and defense groups, respectively; μ_{aak} is a coefficient that defines an anti-air damage potential of *k*-type ship, it is stored inside game engine database.

To calculate the probability of missiles not being destroyed by opposing ships anti-air means, we can use these equations for core and defense groups respectively:

$$Q_{aa(c)} = e^{-\frac{\mu_c}{n}}, \tag{8}$$

$$Q_{aa(d)} = e^{-\frac{\mu_d}{n}}, \tag{9}$$

where *n* is the total number of missiles fired in a single launch.

Total anti-air damage potential coefficients for each group are μ_c and μ_d. Coefficient for a core group is defined by an equation:

$$\mu_c = K^c \mu_{aa}^{c} + K^o \mu_{aa}^{d}, \tag{10}$$

and for a defense group:

$$\mu_d = K^o K^d (\mu_{aa}^{d} + (1 - K^c)\mu_{aa}^{c}), \tag{11}$$

where K^c, K^d, K^o are coefficients that determine the effectiveness of anti-air systems for core and defense groups, and whole squadron respectively.

The effectiveness depends on the ship structure inside a squadron and the covered area [14], [19]. In general, the larger the coverage, the lower the efficiency of ships anti-air systems.

To calculate the coefficient P_{cap}, which defines the probability, in conditions without EW countermeasures, that each missile in launch will successfully find their targets inside the core group. The value is taken from game engine data base and chosen depending on the type of anti-ship missile, [20], [21] the area which is covered by the opposing player ships and the distance from the center of the squadron, and the total number of ships in each group.

To calculate the coefficient P_{ac}, which defines the probability, in the conditions of an active EW, every missile will aim at the targets inside the core group. Similarly, the value is taken from game database and depends on the type of anti-ship missile, the area which is covered by the naval squadron and the distance from the center of the squadron, and the total number of ships in each group [20], [21].

To calculate the probability P_{ad} that in the conditions of active enemy EW each missile will aim at the ship inside the defense group. This defines a number of missiles that will aim at the ships inside the defense group, instead of their originally defined targets from core group:

$$P_{ad} = Q_{ew} - P_{ac}, \tag{12}$$

where Q_{ew} is the coefficient that defines the effectiveness of opposing EW, and the number of missiles that will not change their targets and will be aimed at the ships in the core group.

If all ships in the squadron have the same class and specifications, then we will consider each one of them as target inside the core group and P_{ac} will be equal to Q_{ew}.

This evaluation of probability for an anti-ship missile to capture the indicated target depends on [22], [23] various dynamic factors: the arrangement of the opposing ships squadron, the direction of the launches, the presence of decoy targets alongside actual targets, and the target's proximity to the coastline, which may increase the risk of mistakenly targeting coastal structures.

The probability of destroying targeted *i*-th ship in a group of *N* ships with one launch of *n* missiles can be calculated by the equation

$$W_{i(n)} = 1 - e^{-(\frac{nP_{cap}P_{hom}Q_{aam}(n)Q_{ew}Q_{tech}}{\omega_i})} \tag{13}$$

for each ship in core and defense groups, where P_{hom} is a coefficient defining the probability of a missile to aim at a designated target with self-homing, this coefficient based on a missile and ship class [24]; Q_{ew} is coefficient that defines the number of missiles that are deflected by the opposing player EW; P_{cap} is the probability of a missile successfully capturing designated target [15], [25]; Q_{tech} is the coefficient that defines the technical reliability for the current missile type; ω is the number of missile hits required to destroy the targeted ship.

Q_{aam} is a total probability of missiles evading all anti-air defense of the rival player:

$$Q_{aam(n)} = Q_{fa}Q_{aa(n)}, \tag{14}$$

which is calculated separately for ships in core and defense groups.

When firing at a small formation of opposing ships with total count of *N* ships, while aiming the missiles at the center of the core group, missiles will be distributed evenly among ships inside the group. In this scenario, the likelihood of a missile hitting a ship within the core group can be determined by the simplified formula: $\frac{n}{N}$, where *n* is a total number of missiles fired in a single launch, and *N* is a total number of ships in the formation.

The mathematical expectation for the total number of destroyed ships within a group can be calculated by the formula:

$$\overline{N} = \sum_{i=1}^{N} W_i. \tag{15}$$

Degree of objective completion can be calculated by the formula:

$$W_{tc} = \frac{\overline{N_K}}{N_k}, \tag{16}$$

where $\overline{N}_k$ is the amount of destroyed ships; *N* is total number of targets in core group.

The coefficients for various ship attributes, including anti-air capabilities, ship arrangement within groups, interceptors' ammunition and firepower, missile targeting capabilities, effective range and damage, were gathered and computed from an analysis of diverse literature sources and open tech specifications [11]. All values are stored in the game engine database and some of them are hidden from the players by default. For model testing and further analysis, under various in-game scenarios, we will use simplified values for all coefficients.

In base game scenario, we will set that one missile hit is enough to destroy a ship. With that we can easily separate the missile strikes in our simulation. After calculating the results of each strike, we can update status for every ship in the squadron, depending on the total number of destroyed ships, and just remove them from the calculation for the next strikes.

One of the objectives of our simulation is to calculate the number of missiles and launchers required to successfully carry out the assigned task. In further calculations, for simplicity, the assigned task will always be to destroy all ships in the core group of rival player naval squadron.

If we use the average expected number of successfully destroyed targets as a benchmark, then the necessary force should be capable of achieving this average target number as *N*:

$$\overline{N} = N - \frac{N - \overline{N_{tl}}}{(1-W_{sl})(1-W_{\Sigma})}, \tag{17}$$

where *N* is the number of ships in the core group that must be destroyed; N_{tl} is the total given math expectation of the destroyed ships after a strike.

Beyond the initial objective to calculate the composition of required forces for a combat assignment for a defending player, it's essential to also evaluate the effectiveness of strikes. These evaluations are based on the premise that a specific number of anti-ship missile carriers within the strike groups will still be operational at the time the strikes are launched. These additional calculations are crucial for refining the strike organization strategy, taking into account that the actual composition of forces may vary due to potential losses of carriers during the game scenario.

The potential damage of an anti-ship missile to a specific target is calculated based on a set rule that describes the likelihood of hitting the target [4]. This rule outlines a relationship that involves the target ship's durability, the attributes of the anti-ship missile striking it, and the number of missile hits that result in the target being put out of action, failing, or being destroyed. In certain scenarios, a single hit from an anti-ship missile may be sufficient to destroy the target.

5. Experiment

We will make calculations for different compositions of an opposing naval landing squadron from the attacking player side, with the same missile launcher setup on the defending player side.

1) The first setup for a rival player force will contain only 4 ships of "Type-A1" in the core group. The defending player forces will include 2 launchers with 4 missiles each, 8 in total. Attacking player forces don't have active air support and no active EW.

Q_{fa}, and Q_{ew} coefficients will be equal to 1, because in the current setup there is no air support and EW.

Ship's anti-air weapons potential depends on time range of a missile launch. We can calculate all time parameters using formulas (4) and (5). In the current setup, there are 2 launchers carrying 4 missiles each. τ = 5s is a time between each missile launch. Each launcher will need T_j = 15s and $T_j max$ = 15s because launchers are identical.

Total time required for a launch: $T_a = 15\big(1 + 0.2(2 - 1)\big) = 18$.

For the ships in core group of "Type-A1", we can get from the game database the coefficient defining their anti-air capabilities μ_{aa} = 0.2. Main purpose of ships in the core group in to transport personnel, because of that they have relatively small anti-air damage capabilities.

We can calculate anti-air coefficients for the core and defense groups: $\mu_{aa}^c = 4 * 0.2 = 0.8$, $\mu_{aa}^d = 0$. Also, we can get from the database a coefficient of ships combat efficiency in the core group K_c = 0.55, which depends on a radius of covered area R = 5 km.

Resulting anti-air coefficient for the core group: $\mu_c = 0.55 * 0.8 = 0.44$.

With formula (8), we can calculate the probability of missiles evading core group ships anti-air systems:

$$Q_{aa(c)} = e^{-\frac{0.44}{8}} \approx 0.9465.$$

Core group contains 4 ships with the same type, then P_{cap} = 0.25. We can take auto-aiming coefficient for a missile to capture ships of "Type-A1" from a game database: P_{hom} = 0.9.

Missile reliability Q_{tech} = 0.95. And as we decided before, one missile hit will be enough to destroy the target ω = 1.

Using formula (13), we will calculate math expectation for hitting each ship in the core group:

$$W_i = 1 - e^{-\left(\frac{8*0.25*0.9*0.9465*1*0.95}{1}\right)} \approx 0.802.$$

Mathematical expectation for whole group: $\overline{N} = 4 * 0.802 = 3.2$. Result shows that with 2 launchers and 8 missiles we can anticipate the destruction of 3 out 4 ships in the core group.

Let's make calculations for different numbers of missiles:

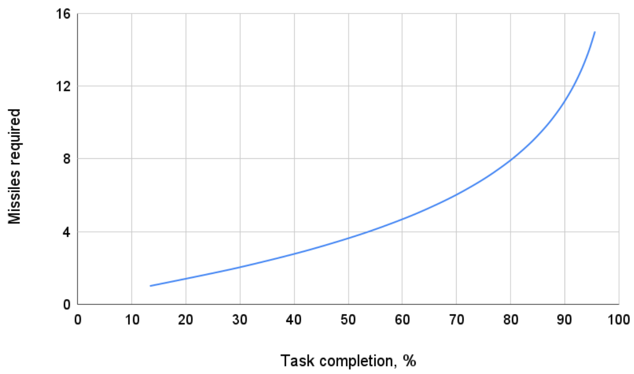

Fig. 1. Missiles needed against the 4 ships in the core group.

Based on the result of our calculations, we can see that to destroy all ships in core group $\overline{N} > 3.8$, we need more than 15 missiles and 4 launchers.

2) Let's add to the attacking player setup the defense group with 4 ships of "Type-D1". We can analyze how effectively defense ships with more powerful anti-air systems can protect ships in the core group. We need to calculate from a defending player side how many missiles he has to add to be able to prevent attacking player naval operation with the new setup.

Q_{fa} = 1, and Q_{ew} = 1, because there is no air support and EW, and time value still the same T_a = 18*s*.

We can get anti-air damage coefficient for ship type "Type-D1" μ_{aa} = 2, ships of this type have better anti-air capabilities. The value for the core group is the same $\mu_{aa}^{c} = 0.8$. For the defense group $\mu_{aa}^{d} = 4 * 2 = 8$.

K^c = 0.55, K^d = 0.55, K^o = 0.4 are coefficient of anti-air efficiency for core group, defense and whole squadron, respectively.

Using formula (10), we can calculate core group anti-air damage potential:

$$\mu_c = 0.55 * 0.8 + 0.4 * 8 = 3.64.$$

Using formula (11), we can calculate defense group anti-air damage potential:

$$\mu_d = 0.4 * 0.55(8 + (1 - 0.55) * 0.8 \approx 1.84.$$

The probability of missiles evading anti-air system of every ship in core group and defense group:

$$Q_{aa(c)} = e^{-\frac{3.64}{8}} \approx 0.634, \qquad Q_{aa(d)} = e^{-\frac{1.84}{8}} \approx 0.795.$$

P_{cap} value is different for ships in separate groups. For each ship inside the core group: $P_{cap} = \frac{0.6}{4} = 0.15$. For each ship inside the defense group: $P_{cap} = \frac{0.36}{4} = 0.09$. P_{hom} = 0.9 for core group ships. For ship type "Type-D1" P_{hom} = 0.7.

Missile reliability and number of missiles needed to destroy the target are the same Q_{tech} = 0.95, ω = 1.

With formula (13), we will calculate math expectation of destroying ships in the core and defense groups:

$$W_{i(c)} = 1 - e^{-\left(\frac{8*0.15*0.9*0.634*1*0.95}{1}\right)} \approx 0.478,$$

$$W_{i(d)} = 1 - e^{-\left(\frac{8*0.09*0.7*0.795*1*0.95}{1}\right)} \approx 0.316.$$

$\overline{N_c} = 4 * 0.478 = 1.912$, $\overline{N_d} = 4 * 0.316 = 1.264$ are total numbers of destroyed ships in core and defense groups.

Against the whole squadron, we can expect to destroy ~3 ships: $\overline{N} = 1.912 + 1.264 = 3.176$.

The main goal of defending player is to destroy all 4 ships in the core group, and with 8 missiles we can anticipate to destruction of only 2 ships.

We can make additional calculations for the same setup to find the optimal amount of missile required to destroy 4 ships in the core group:

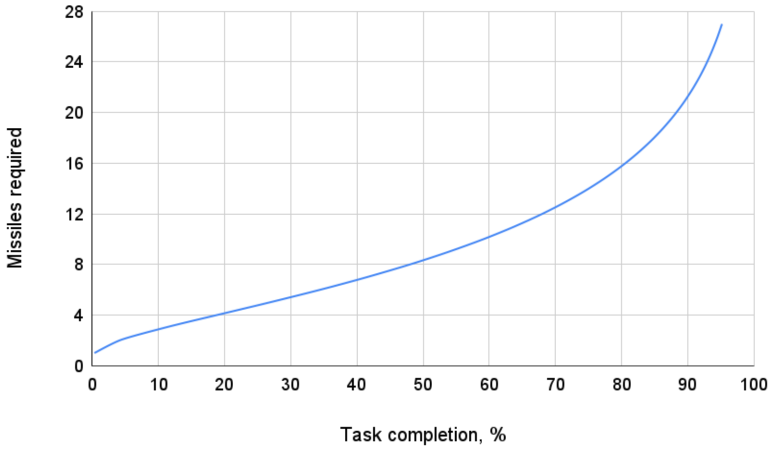

Fig. 2. Number of missiles required with an addition of 4 defense ships.

From the graph, we can see that to complete the assigned task, the defending player needs 27 missiles.

One of the main problems of anti-ship missiles is the addition of side targets which decreased the probability of aiming at the ships inside the core group.

3) Let's update the current setup by adding air support to the attacking player forces in the form of 2 interceptors of type "Type-FJ1".

$Q_{ew} = 1$, there is no EW.

From the game database for active interceptors of chose type, we can get the aiming and damage coefficients:

$P_{\mu ak} = 0.75$, $\mu_k = 2.5$.

Using formula (1), let's calculate the probability for a missile to dodge attacking player interceptors:

$$Q_{fa} = 1 - 0.7(1 - e^{-\frac{2*2.5}{8}}) \approx 0.675.$$

$\mu_c = 3.64$ and $\mu_d = 1.84$, coefficients for the anti-air potential are the same.

The probability of missiles evading anti-air system of every ship in core group and defense group:

$$Q_{aa(c)} = e^{-\frac{3.64}{8*0.675}} \approx 0.509, \qquad Q_{aa(d)} = e^{-\frac{1.84}{8*0.675}} \approx 0.711.$$

The other coefficients are the same: $P_{cap(c)} = 0.15$, $P_{cap(d)} = 0.09$; $P_{hom(c)} = 0.9$, $P_{hom(d)} = 0.7$; $Q_{tech} = 0.95$; ω = 1.

Math expectation of destroying ships in the core and defense groups:

$$W_{i(c)} = 1 - e^{-\left(\frac{8*0.15*0.9*0.509*0.675*0.95}{1}\right)} \approx 0.297,$$

$$W_{i(c)} = 1 - e^{-\left(\frac{8*0.09*0.7*0.711*0.675*0.95}{1}\right)} \approx 0.205.$$

Total number of destroyed ships in opposing naval squadron: $\overline{N} = 4 * 0.297 + 4 * 0.205 = 2.008$.

Let's make additional calculations for the same setup:

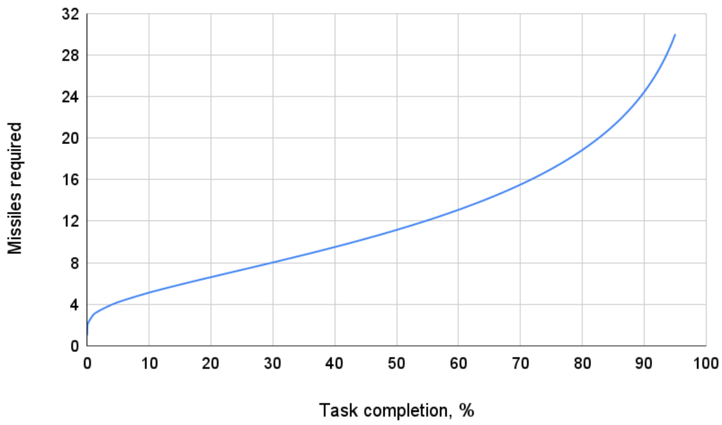

Fig. 3. Missiles needed against opposing forces with interceptors.

To complete the assigned task, the defending player needs more than 30 missiles.

Results show us that interceptors of the chosen type are effective against the small number of anti-ship missiles. So defending player should prepare in their setup additional missiles for each opposing interceptor.

4) In the next setup, we will add active EW on the attacking side.

Q_{ew} = 0.5.

Based on the number and the area covered by the core group: P_{ac} = 0.3.

EW coefficient for defense group: P_{dc} = 0.5 – 0.3 = 0.2.

All the other parameters will be the same.

Math expectation of destroying ships in the core and defense groups:

$$W_{i(c)} = 1 - e^{-\left(\frac{8*0.15*0.9*0.509*0.675*0.3*0.95}{1}\right)} \approx 0.1,$$

$$W_{i(c)} = 1 - e^{-\left(\frac{8*0.09*0.7*0.711*0.675*0.2*0.95}{1}\right)} \approx 0.045.$$

Total number of destroyed ships in core and defense groups: $\overline{N_c} = 4 * 0.1 = 0.4$, $\overline{N_d} = 4 * 0.045 = 0.18$.

Total number of destroyed ships: $\overline{N} = 0.4 + 0.18 = 0.58$.

We can make additional calculations for the same setup:

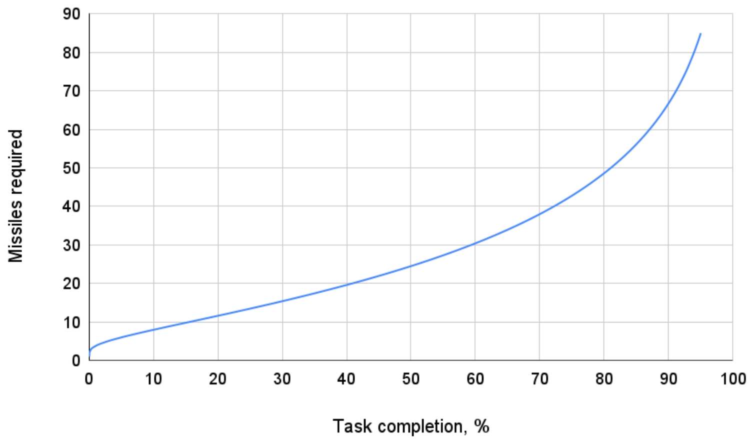

Fig. 4. Missiles needed with active EW from attacking.

To complete the assigned task, the defending player needs more than 85 missiles.

The results show the effectiveness of the EW on the attacking player side against the anti-ship missiles. For defending player, it is crucial to prepare accordingly against such setup of attacking forces.

Using this method, the defending player can make all necessary calculations against every possible setup of the attacking player forces and prepare the optimal amount of resources to prevent opposing naval operation.

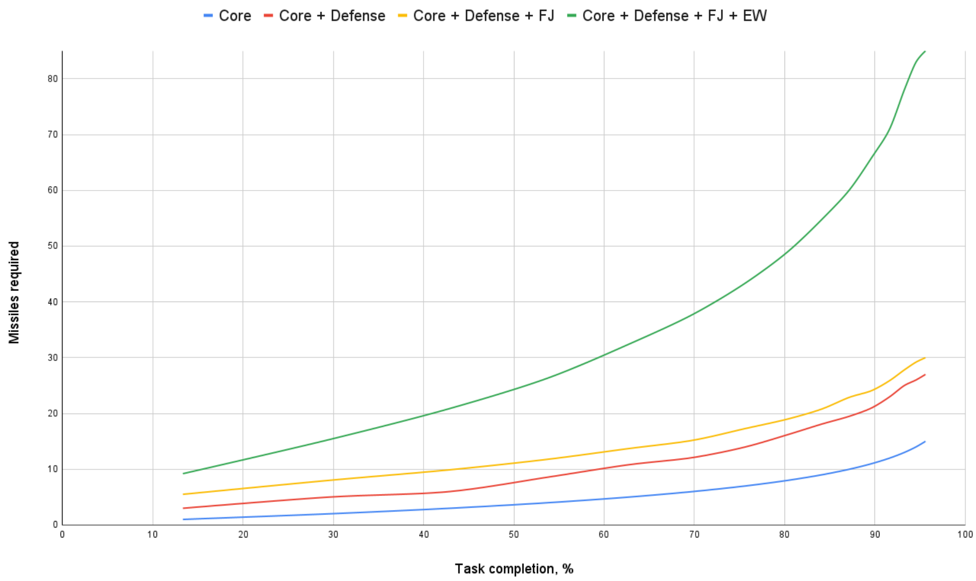

Fig. 5. Missile strike effectiveness against different attacking setups.

6. Conclusion

A model has been built for calculating the anti-ship missile damage with taking into account all possible components of naval landing operation, such as: ships carrying the landing assets, escort and supply ships with different classes, air assistance in the form of interceptors, all kinds of anti-air systems and reconnaissance systems supporting them, and different setups of the rival player forces, containing all these components.

The optimal number of missiles required to complete the assigned task of preventing rival player naval landing operation by destroying all ships in a naval landing group (core group) was defined. Developed model allows us to choose from multiple defense setups and chose the best one in current in-game scenario.

Experimental calculations show the effectiveness and multiple possible use cases for the model we have built. Comparing the results of calculations for different setups of rival player ship squadron, we can define the impact for each component of naval operation on its success, such as different classes of ships, air support, reconnaissance and EW systems.

Such tool gives players and game AI an opportunity to make fast and effective decisions for planning against rival activities and allows us to relatively accurately predict possible outcomes of the game scenario and make all necessary preparations regarding size of salvo, the timings and required number of missiles strikes for countering rival player naval landing operation.

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Симуляція ракетного удару у відеоігровому рушієві

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Анотація

У сфері сучасних комп'ютерних ігор (особливо в жанрі бойових стратегій, реалістичних стрільців від першої особи та інших військових ігор) складність віртуальних морських бойових механізмів і стратегій значно зростає. Збільшується попит на летальніші симуляції, щоб забезпечити максимально реалістичний досвід і більш складний ігровий процес для всіх гравців. Метою цього дослідження є створення моделі та інструменту, які можуть точно передбачити вплив протикорабельних ракет на кораблі, які беруть участь у різних ігрових сценаріях. Охоплюючи широкий спектр типів ракет, стратегій висадки, класів кораблів, типів літаків, варіантів систем розвідки, технологій радіоелектронної боротьби та різних систем протиповітряної та протиракетної оборони, симуляція включає як наступальні, так і оборонні сценарії, щоб переконатися у важливості протикорабельних ракет в ігрових сценаріях. По-перше, дослідження зосереджено на вдосконаленні моделей прогнозування для розрахунку шкоди, завданої ракетними ударами військово-морським силам суперника. По-друге, він спрямований на вдосконалення алгоритмів для визначення необхідної кількості ракет, щоб запобігти просуванню сил суперника, таким чином максимізуючи оперативну ефективність і результативність у оборонних місіях.

Ключові слова: комп'ютерна гра; протикорабельні ракети; наведення ракети; морський десант; система моделювання.