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MODELING OF AN ATTACK MISSION BY STRIKE DRONES UNDER ACTIVE ENEMY COUNTERACTION

*The rapid growth of innovation in modern warfare has led to the need to consider the enemy's ability to build defenses using modern anti-drone measures when planning offensive missions with strike drones. Therefore, researching preventive actions is relevant when planning a massive attack aimed at overcoming obstacles to the movement of strike drones to enemy targets. The publication focuses on the development of analytical and simulation models to plan an attack while minimizing the risks posed by enemy anti-drone actions. **The goal of this research** is to develop a set of mathematical and simulation models for planning the movement of a swarm of attack drones under active enemy countermeasures. **The tasks that need to be solved are** as follows: systematically analyse actions for planning an attack mission in conditions of dynamic changes in the battlefield; select a subset from a set of relevant enemy targets for attack; create the required number of strike drones for attack in conditions of limited capabilities; create confusing trajectories for strike drones to successfully hit enemy targets; develop an algorithm for forming a flight route with minimal risk of drones being shot down (lost); and create a simulation model to simulate the movement of a swarm of strike drones towards targets under active enemy countermeasures. Mathematical methods and models used: system analysis to create a logical sequence of actions for conducting an attack with strike drones; qualitative and quantitative assessment of the characteristics of possible enemy targets; lexicographic ordering of options for selecting a subset of relevant enemy targets; integer (Boolean) to calculate the number of strike drones that will be involved in the attack; agent-based simulation modeling to form the movement of strike drones in enemy countermeasure conditions. The following **results** were obtained: a proposed systematic representation of the planning of an attack mission with strike drones under conditions of dynamic changes in circumstances on the battlefield; a justified selection of a subset of relevant targets for a massive attack; the required number of attacking drones was calculated under conditions of limited capabilities; an algorithm was developed to create a route for strike drones with minimal flight risks; and an agent-based model was created to simulate the flight of a swarm of strike drones for various scenarios of active countermeasures by the breacher. **Conclusions:** The results of the study provide a scientific basis for developing a plan for an attack mission by a swarm of strike drones under active enemy countermeasures, thereby facilitating the integration of air and ground combat operations and enabling the successful execution of the planned military operation. The novelty of the proposed approach lies in the scientific justification of the plan for an attack mission using strike drones in the face of active enemy countermeasures and dynamic battlefield conditions, supported by a developed set of original analytical and simulation models.*

Key words: attack drone swarm; attack mission; current enemy targets; minimization of drone movement risks; optimization of the number of attack drones; simulation-based multi-agent modeling of attack drone movement.

1. Introduction

Innovative technological and tactical solutions are changing the nature and strategy of combat operations on the battlefield in modern warfare [1]. The military pays particular attention to the use of unmanned aerial vehicles (UAVs), which have contributed to the emergence of new areas of air operations on the battlefield and behind enemy lines [2]. The creation of various types of drones (strike, reconnaissance, decoy drones, etc.), as well as the ability to form them into swarms (groups, flocks, etc.), requires the improvement

of the process of planning offensive missions against enemy targets [3, 4]. This is especially important when planning a massive attack, given the improved tactics of the enemy for using anti-drone systems (drone interceptors, laser guns, mobile military groups with air defense systems, etc.) [5, 6]. Real threats exist to the flight of a swarm of drones to their targets, which leads to the need to search for routes with relatively safe trajectories in conditions of dynamic changes in the battlefield [7, 8]. Forming flight routes for a swarm of strike drones is a difficult task in complex conditions that arise on the battlefield [9, 10].



Thus, considering the above, we can conclude that research on planning a massive attack with strike drones in conditions of active enemy counteraction is relevant.

1.1. Motivation

Modern planning and flight control systems based on artificial intelligence (AI) for strike drones enable rapid monitoring of changing battlefield conditions, particularly in response to enemy anti-drone actions [11, 12]. Therefore, the task of correcting (replanning) the routes of attack drones arises when circumstances on the battlefield change. This affects the risks of achieving objectives, drone swarm flight time, and drone shooting down (loss). Finding relatively safe flight routes is a complex task, and solving it enables a successful attack mission with minimal losses of strike drones. Therefore, the primary task is to form the flight route of a swarm of strike drones to enemy targets under dynamic changes in battlefield circumstances.

1.2. State of the Art and problem statement

The enemy's actions aimed at destroying strike drones in flight have led to route formation problems, given the emergence of new tactical actions and improvements in anti-drone measures [13, 14]. Some problems are being solved, but new ones require further research. Let us briefly review the methods for solving these problems:

1. Flight planning for attack drones, considering modern enemy countermeasures associated with the development of new anti-drone systems.

In [15], a flight protection mechanism called IoD-JAPM is proposed, ranging from airspace availability analysis to potential drone trajectory re-planning. An experimental evaluation was conducted using simulations to compare IoD-JAPM with the baseline solution and the existing approach, varying the IoD topology and the number of jammers in the environment. In [16], the authors investigated interference-resistant UAV path-planning strategies for data collection in Internet of Things (IoT) networks, in which a typical UAV can learn an optimal trajectory to avoid jamming attacks. To combat such attacks, an intelligent anti-jamming strategy for UAVs is developed, and the optimal trajectory of a typical UAV is obtained using a dual deep Q-network (D3QN).

2. The dynamics of changing circumstances on the battlefield must be considered in drone flight planning and control systems.

The effectiveness of military drones depends on the ability of the swarm to collectively act in complex battlefield conditions, where the target is constantly changing. Article [17] proposes an algorithm for

dynamic mission planning for multiple UAVs based on a time window mechanism within a distributed formation structure. The particle swarm optimisation algorithm was improved by introducing a specific particle coding method and a competitive co-evolutionary population update strategy to increase the solution speed and accuracy of the mission planning model. The authors of article [18] proposed an algorithm that provides cooperative swarm service and maximizes the target bombing area. Multi-agent reinforcement learning (MARL) is used for the cooperation of military UAVs under dynamic target conditions.

3. Formulation of new strategies for conducting military missions using strike drone swarms in the context of tactical and technological innovations.

Technological progress has led to increased drone capabilities and reliability and reduced production costs. Military strategists must include responses to potential drone swarms in their operational scenarios. Article [19] identifies the evolution of threats associated with drones and their swarms and makes possible countermeasures. Practical solutions are proposed, including the development and deployment of specialized anti-drone units. Publication [20] presents research on planning attack missions using strike UAVs. A set of models has been developed that allows for the planning of massive attacks by strike drones, the necessary combat potential of a swarm of attacking drones has been formed, and waves of strike drones for destroying enemy targets have been substantiated.

4. Real-time use of AI tools to fly a swarm of drones.

In [21], UAV swarm clustering is performed using a modified Gaussian distribution with machine learning methods. A swarm of UAVs is formed based on a Gaussian distribution using a real set of data about birds, and the modified Gaussian swarm is then clustered using the K-means clustering algorithm. In [22], a non-invasive brain-computer interface (BCI)-based control of a drone swarm is proposed. Endogenous paradigms specialized for controlling a drone swarm are developed, and various tasks are classified based on EEG.

5. Improvement of UAVs' tactical and technical characteristics to increase the efficiency and effectiveness of attack missions.

The authors of article [23] conducted a systematic assessment of UAV vulnerabilities, privacy risks, and viable solutions. Based on a cross-layer taxonomy, both technical and operational aspects were examined to evaluate the effectiveness of security measures in terms of performance, feasibility, and maturity. Technical parameters influencing the use of UAVs in offensive

missions, including accuracy, latency, cost, and energy efficiency, were highlighted.

6. New (innovative) algorithms for planning flight routes for strike drones in active enemy counteraction conditions are being developed.

Article [24] analyzes methods of mathematical modeling of the use of strike UAV swarms and algorithms for their implementation. The task of distributing strike UAVs in a swarm should be solved using artificial intelligence methods, namely neural networks. Further research directions include the creation of more specialized multilayer neural networks for controlling the use of a swarm of strike UAVs and the dynamic distribution of a swarm of strike UAVs among objects of non-stationary group targets of the enemy, considering the priority of their elements.

7. Real-time correction (replanning) of the initial flight plan for strike drones under dynamic battlefield conditions.

Frameworks, simulations, and auxiliary algorithms for dynamic mission planning, which involves replanning in the middle of a mission based on new information, are among the new areas [25]. An attempt has been made to identify leading academic algorithms that could support dynamic mission planning. Article [26] discusses a path planning algorithm that aims to develop a route penetration strategy based on an improved A-Star algorithm to solve replanning problems for UAVs in a complex three-dimensional dynamic environment. Emerging threats are considered in three threat scenarios that approximate a real combat environment.

8. Multi-variant scenarios for creating anti-drone defense against massive strikes by drones.

The authors of study [27] proposed a systematic framework for planning defensive actions against large-scale attacks by enemy strike drones. A multi-agent simulation model was developed to analyze and predict possible scenarios of enemy strike drones' launch and flight towards critical military and civilian infrastructure locations. Article [28] presents an optimization model for determining the structure of the armed forces based on reference modules with desired capabilities, which allows for the implementation of specific operational concepts, considering operational and cost criteria. The modeling is based on a step-by-step analysis with an introduced scenario, a possible enemy structure, and a specific task.

9. Problem of fast and secure transmission of relevant intelligence data to the UAV control system for flight correction when circumstances change on the battlefield.

The paper [29] analyzes the impact of specialized cyberattacks on the effectiveness of UAVs, as well as cryptographic methods that can be used to ensure data

transmission security, authentication, confidentiality, and information integrity. A basic and improved UAV protection system architecture based on selected protocols has been developed. A previous study [30] addressed the problem of securing the MAVLink communication protocol. An additional security layer is introduced to provide encryption and protection of the protocol, ensuring secure communication between the UAV and the GCS without affecting performance and efficiency.

This is not a complete list of problems, which continues to be replenished with new ones in the conditions of modern warfare, indicating the relevance of solving the problem of planning (replanning) the flight of a swarm of strike drones in the conditions of dynamic changes in the battlefield. An analysis of publications on the above list of problems has shown the relevance of conducting research on the flight planning of a swarm of strike drones in active enemy counteraction conditions. The analysis of approaches to finding relatively safe flight routes for drones to targets in conditions of active enemy countermeasures revealed the shortcomings of existing approaches and the advantages of the proposed approach in the study:

- in most studies, the authors use mathematical (analytical) models that do not allow for a full study of dynamic events that occur in real time and reflect changes in circumstances on the battlefield;

- proposed approach solves the problem of the effective use of UAVs (individual, swarm, group, etc.) through the integrated use of optimization models and models of the dynamic behaviour of objects (drones) under active enemy counteraction conditions.

- use of simulation models to describe the dynamics of events on the battlefield allows us to consider time as the main factor in the development of causal events that reflect the real situation and objects (drones, air defense systems, etc.);

- It is possible to replan the flight of drones in real time when circumstances change on the battlefield using the developed set of models. Using real data from the domestic DELTA system allows you to quickly form new, relatively safe flight routes (flight missions) under active enemy countermeasures.

1.3. Objectives and methodology

There is a dilemma between the need to plan the flight path of a swarm of strike drones in such a way as to maximally hit enemy targets and the imperfection of existing methods and models, which do not fully account for the dynamics of changing circumstances on the battlefield and active enemy countermeasures to destroy UAVs, using a modern arsenal of anti-drone

measures (mobile air defense groups, anti-aircraft drones, interceptor drones, electronic warfare, etc.).

This study aims to develop a set of mathematical and simulation models for planning the movement of a swarm of strike drones under active enemy counteraction.

In accordance with the study's stated aim, the following tasks need to be solved:

1. To create a systematic representation of actions for planning the movement of strike drones in dynamic battlefield conditions.

2. To justify the selection of a subset of the current targets of the enemy for destruction by strike drones.

3. To form the fleet of strike drones necessary for conducting an offensive mission.

4. Plan complex flight paths for a swarm of strike drones under active enemy opposition conditions.

5. To create an algorithm for forming flight routes for strike drones to enemy targets with minimal drone destruction risk.

6. To develop a multi-agent simulation model for simulating a massive attack using a swarm of strike drones.

7. Provide an illustrated example of the movement planning of strike drones in active enemy counteraction conditions.

The article is structured as follows:

- Section 2 is devoted to a systematic analysis of actions for planning a massive attack using a swarm of strike drones;

- Section 3 deals with the selection of attack targets in the form of a subset of the current targets of the enemy.

- Section 4 calculates the number of strike drones needed to successfully perform an attack mission in conditions of increased risk of enemy countermeasures;

- Section 5 describes the formation of the components of the flight path of strike drones to hit enemy targets;

- Section 6 presents the creation of an original algorithm based on simulation modeling, for forming the movement of strike drones in real time and with possible movement correction;

- Section 7 describes the development of the simulation of drone movement in various scenarios of enemy drone actions;

- Section 8 illustrates, by example, the feasibility and effectiveness of the proposed approach for planning a massive attack on enemy targets using a swarm of strike drones;

- Section 9 presents a discussion of the scientific results and their presentation in the form of a methodology that emphasizes the significance of the

research for practical application;

- Section 10 concludes the article by summarizing the conclusions and providing prospects for further research and the creation of applied information technology for planning combat operations using a swarm of strike drones in active enemy opposition conditions.

2. Features of planning attack missions of strike drones in conditions of active enemy counteraction

Analysis of attack missions using strike drones has identified several significant factors that influence the formation of strike drone flight plans for enemy targets:

1. Increased pace of change on the battlefield. The enemy is constantly changing its tactics to actively counter strike drones using mobile fire groups equipped with modern anti-drone weapons.

2. Emergence of new technologies for creating anti-drone measures that significantly affect the risks of conducting an attack mission using a swarm of strike drones. For example, the emergence and active use of interceptor drones

3. The need to update the initial flight plan for strike drones (correction, re-planning) due to changing battlefield circumstances.

4. Using complex flight paths to minimize the risk of UAVs being lost or shot down.

5. Improvement of the tactical and technical characteristics of UAVs to ensure the stealth of strike drones flying to enemy targets.

6. Minimizing the risks of achieving goals in conditions of active enemy opposition.

In modern hybrid warfare, there is a growing number of innovations (tactical, technological, etc.) that require the creation of new methods for planning offensive actions using swarms of strike drones.

The formation of a flight plan begins with an analysis of possible enemy targets for a massive attack using a swarm of strike drones. Target selection is primarily related to military attack targets (e.g., concentrations of military personnel and equipment, command posts, and communication centres) and dual-use infrastructure facilities (e.g., transportation, engineering structures, industrial enterprises, and logistics warehouses). Next, the possibility of creating the necessary strike potential of a swarm of strike drones capable of destroying enemy targets must be assessed. The next step is to develop a plan for distributing the swarm of strike drones in flight into groups directed at enemy targets. The most difficult stage of planning is the formation of flight routes for a swarm of strike drones under active enemy

counteraction conditions. Reducing flight risks from active enemy countermeasures will ensure successful target destruction. The dynamics of changing circumstances on the battlefield require corrections (replanning) to the drone swarm flight to achieve the military mission objectives. Predicting possible scenarios of enemy countermeasures, using anti-drone measures, and changing circumstances on the battlefield requires multi-variant simulation of drone movement over time, using modern simulation modelling methods in a multi-agent form.

The following possible countermeasures by the enemy against an attack with strike drones were analysed:

1. Formation of false targets that weaken the drone swarm's strike potential.
2. Operational relocation of anti-drone equipment using mobile fire teams.
3. Various anti-drone measures are used to protect targets from massive attacks by strike drones.
4. Improving the effectiveness of anti-drone warfare by implementing new operational and tactical measures.

When planning a massive attack using a swarm of strike drones, it is important to accurately assess the possible level of damage to enemy targets. This affects the planning of waves of strike drones, which ensures the complete destruction of targets [31].

3. Justification for selecting a subset of the current targets of the enemy for destruction by strike drones

While planning operational and tactical actions on the battlefield, it is important to identify strategically important targets so that their destruction ensures the success of defensive and offensive measures, enabling the seizure of the military initiative from the enemy.

The initial stage of planning an attack mission using a swarm of strike drones is selecting relevant enemy targets. The number of enemy targets may be such that creating the necessary strike potential of a drone swarm is impossible under limited conditions. Therefore, the task is to form a subset of relevant targets that are a priority for a massive strike-drone attack.

Let us assume that, after analyzing intelligence data and the opinions of experts and military leadership, (N) possible enemy targets that need to be hit have been identified. The limited capabilities of the existing set of strike drones do not allow all (N) targets to be hit simultaneously, so a subset of active targets must be selected for the attack plan. The number (K) of possible subsets from the set of targets (N) can be estimated using the following combinatorial calculation:

$$K = 2^N - 1.$$

Generating a set of possible target subsets using a binary counter. Consider an example where $N=4$. The number of possible subsets of relevant targets will be as follows:

$$K = 2^N - 1 = 2^4 - 1 = 15.$$

Here are some options for possible subsets of the enemy's goals in the form of binary counter values:

1. 0001	8. 1000	
2. 0010	9. 1001	
3. 0011	10. 1010	
4. 0100	11. 1011	
5. 0101	12. 1100	(1)
6. 0110	13. 1101	
7. 0111	14. 1110	
	15. 1111	

The entire set of possible subsets of the enemy's current objectives is represented in 15 variants.

Here, the first position is associated with the first objective, the second with the second, and so on. For example, variant (11) means selecting a subset of current objectives that includes the enemy's first, third, and fourth objectives. Options with one target: 1, 2, 4, 8.

However, resource constraints do not allow the selection of option 15. Therefore, a search for a rational option arises in the form of a subset of targets (options 3, 5, 6, 7, 9, 10, 11, 12, 13, and 14). This search is illustrated below with an example.

Given the limited possibilities for creating a swarm of strike drones, let us form the indicators that we will use to select the desired subset of the enemy's current targets:

1. Significance of damaging the j -th subset of current targets for subsequent military operations – Z_j .

It depends on the significance of the individual targets to be destroyed.

2. The strike capability required to destroy all targets in the j -th subset of the enemy's current targets – P_j .

3. Time required to perform an attack on the j -th sub-group of targets. It depends on the number of targets and their locations on the battlefield (related to the drone swarm's flight range) – T_j .

Reducing the time allows for a surprise attack and reduces the risk of strike drones being shot down (losing).

4. The risk of conducting a successful offensive mission against the j -th subset of the current targets of the enemy – R_j .

Depends on the availability and quantity of the enemy's protective equipment.

The indicators (Z_j, P_j, T_j, R_j) can be given in both qualitative and quantitative metrics, depending on their representation's possibility. Let the significance (Z_j) be represented on a point scale ($0 \div 10$), the striking potential (P_j) in kg of explosives, and the time required to carry out the attack (T_j) in minutes. The risk of a successful attack mission (R_j) will be represented in Latin letters:

- G – relatively low risk (green),
- O – medium risk (orange),
- R – significant risk (red).

Depending on the purpose of the attack mission, a priority list of indicators can be generated using a swarm of strike drones. Let us assume that the military has established the following priority list of indicators:

:

$$Z_j, R_j, P_j, T_j, \quad (2)$$

where significance (Z_j) comes first.

The selection of the most important indicator under resource constraints depends on the objectives of military leadership in planning strike drone operations. For example, instead of the significance of target engagement (Z_j) in sequence (2), the time required to conduct an attack can be used, which ensures the element of surprise. In this case, time (T_j) will take the first position in (2). Optimizing indicators under limited capabilities involves seeking a compromise solution.

Next, it is necessary to indicate the improvement direction for each indicator:

$$Z_j \uparrow, R_j \downarrow, P_j \uparrow, T_j \downarrow. \quad (3)$$

These areas for improvement will be used to compare options for enemy target subsets.

For example (1), a table with assessments of indicators (Table 1) that were developed by military experts will be used later to select the desired option for a subset of relevant enemy targets.

Consider the options for subsets of the enemy's current objectives in the form of a set of tuples of indicator estimates (Z_j, R_j, P_j, T_j):

$$\begin{array}{ll}
 1. 4, R, 10, 60 & 8. 1, G, 60, 30 \\
 2. 3, O, 20, 50 & 9. 5, R, 70, 60 \\
 3. 7, O, 30, 50 & 10. 4, O, 80, 50 \\
 4. 2, G, 30, 40 & 11. 8, R, 90, 60 \\
 5. 6, R, 40, 60 & 12. 3, G, 90, 40 \\
 6. 5, O, 50, 50 & 13. 7, R, 100, 60 \\
 7. 9, R, 60, 60 & 14. 6, O, 110, 50 \\
 & 15. 10, R, 120, 60
 \end{array} \quad (4)$$

Table 1

№	Enemy targets				Z	R	P	T
	1	2	3	4				
1.	0	0	0	1	4	R	10	60
2.	0	0	1	0	3	O	20	50
3.	0	0	1	1	7	O	30	50
4.	0	1	0	0	2	G	30	40
5.	0	1	0	1	6	R	40	60
6.	0	1	1	0	5	O	50	50
7.	0	1	1	1	9	R	60	60
8.	1	0	0	0	1	G	60	30
9.	1	0	0	1	5	R	70	60
10.	1	0	1	0	4	O	80	50
11.	1	0	1	1	8	R	90	60
12.	1	1	0	0	3	G	90	40
13.	1	1	0	1	7	R	100	60
14.	1	1	1	0	6	O	110	50
15.	1	1	1	1	10	R	120	60

To identify the preferred options, we will use lexicographic ordering, considering directions for improving indicators (3). As a result of ordering, we have the following list of options for subsets of the current goals of the enemy:

$$\begin{array}{ll}
 15. 10, R, 120, 60 & 6. 5, O, 50, 50 \\
 7. 9, R, 60, 60 & 9. 5, R, 70, 60 \\
 11. 8, R, 90, 60 & 10. 4, O, 80, 50 \\
 3. 7, O, 30, 50 & 1. 4, R, 10, 60 \\
 13. 7, R, 100, 60 & 12. 3, G, 90, 40 \\
 14. 6, O, 110, 50 & 2. 3, O, 20, 5 \\
 5. 6, R, 40, 60 & 4. 2, G, 30, 40 \\
 & 8. 1, G, 60, 30
 \end{array} \quad (5)$$

At the top of the ordered set of evaluation tuples are the most priority options for attacking the current targets of the enemy. However, there are limited capabilities (P^*) for forming the strike potential of a drone swarm (for example, $P^* = 60$ kg of explosives). Therefore, only those options for which $P_j \leq 60$ kg of explosives should be considered. The following shortened list of options for subsets of the current targets of the enemy has been formed:

$$\begin{array}{l}
 7. 9, R, 60, 60 \\
 3. 7, O, 30, 50 \\
 5. 6, R, 40, 60 \\
 6. 5, O, 50, 50 \\
 1. 4, R, 10, 60 \\
 2. 3, O, 20, 50 \\
 4. 2, G, 30, 40 \\
 8. 1, G, 60, 30
 \end{array} \quad (6)$$

As a result, a shortlist was formed, headed by option 7, a subset of the enemy's current targets that can be used to plan an attack mission using a swarm of strike drones. It has the following characteristics:

- used to attack the second, third, and fourth enemy targets;

- significance of hitting enemy targets is quite high – 9 points;
- risk of a successful operation is high – R;
- required combat potential – 60 kg of explosives;
- flight time of a swarm of strike drones to targets – 60 minutes.

Therefore, the task of identifying relevant enemy targets to strike during a swarm-based attack mission was set and solved in this section. The following indicators of enemy targets were considered: significance, drones' required strike potential, time of the attack mission, and risk of a successful military operation. Limitations on creating the necessary strike potential of a drone swarm to target all possible enemy targets led to dividing the target set into subsets to find a rational option for conducting an attack with a swarm of strike drones. It was assumed that the indicators' values could be specified in both quantitative and qualitative terms to identify rational targets for the enemy's current attack. Lexicographic ordering of the subsets of the enemy's current targets was used to identify the attack mission's priorities. The limited options for creating drone strike potential reduced the list of options. The choice of the desired subset of enemy targets for the attack mission was justified using a swarm of strike drones.

4. Formation of the number of strike drones required for conducting an attack mission

Planning an attack mission using a swarm of strike drones involves dividing the UAVs into groups during flight, which are directed at enemy targets for destruction. The number of UAVs in the swarm and groups depends on the creation of the strike potential (V_i , $i = \overline{1, N}$), required to destroy the i -th enemy target. However, active enemy countermeasures, using mobile fire groups (MFG) and anti-drone measures (ADM), necessitate the creation of such strike potential of the drone swarm (V_i'), that takes into account the possibility of strike drones being shot down or lost. The increase in strike potential ($\Delta V_i = V_i' - V_i$) depends on the activity of the enemy's countermeasures and the characteristics of the AD used to protect targets. The limited capabilities to create the required strike potential of a drone swarm do not allow for the full creation of the necessary value (ΔV_i) to reduce the risks (R_i) of successfully completing an attack mission. Therefore, the task arises to increase the strike potential (ΔV) in such a way that the acceptable values of the risks (R_i') of shooting down (losses) of strike drones are considered. This raises the optimization problem of

determining the value of ΔV for all selected targets under limited capabilities, considering the risks of striking (shooting down) strike drones. The following forms of the optimization problem are possible:

1. $\min \Delta V$, with restrictions on the acceptable risks of shooting down (losing) strike drones:

$$R_i \leq R_i', \text{ for all } i = \overline{1, N} \quad (7)$$

$$2. \min R, R = \sum_{i=1}^N R_i, \quad (8)$$

with restrictions on the permissible value $\Delta V'$, which is connected with limited capabilities to create the necessary combat potential of strike drones to destroy targets under active enemy countermeasures:

$$\Delta V \leq \Delta V', \Delta V = \sum_{i=1}^N \Delta V_i.$$

These optimization problems are addressed using integer (binary) programming. The binary decision variable z_{ik} , is defined as follows:

$$z_{ik} = \begin{cases} 1, & \text{if for the formation } \Delta V_i \\ & \text{it is necessary to add } k \text{ drones} \\ & \text{in group } i\text{-}u, \text{ which is aimed} \\ & \text{at the } i\text{-}u \text{ enemy target,} \\ 0, & \text{otherwise.} \end{cases} \quad (9)$$

With the variable z_{ik} , the first optimization problem can be described as follows:

$$\min \Delta V, \Delta V = \sum_{i=1}^N V_i = \sum_{i=1}^N \sum_{k=1}^{n_i} k z_{ik}, \quad (10)$$

with considering restrictions on permissible values of risks of shooting down (losses) of strike drones:

$$R_i \leq R_i', R_i = \sum_{k=1}^{n_i} r_{ik} z_{ik}, \text{ for all } i = \overline{1, N}, \quad (11)$$

where n_i is the maximum permissible number of strike drones that can be allocated to destroy the enemy's i -th target;

r_{ik} is the risk of shooting down (losing) a group of k strike drones aimed at the i -th enemy target. The value of r_{ik} is based on the opinions of military experts with experience in modern hybrid warfare.

For the second optimization problem, we have the following formal formulation:

$$\min R, R = \sum_{i=1}^N R_i = \sum_{i=1}^N \sum_{k=1}^{n_i} r_{ik} z_{ik}, \quad (12)$$

with considering on the permissible number of strike drones that can be added in active enemy counteraction:

$$\Delta V \leq \Delta V', \quad \Delta V = \sum_{i=1}^N \Delta V_i = \sum_{i=1}^N \sum_{k=1}^{n_i} k z_{ik}. \quad (13)$$

Therefore, in this section, it was proposed and decided to form a swarm (group) of strike drones in conditions of active enemy opposition, which uses mobile fire groups and modern anti-drone measures. While planning the strike potential of drones to hit targets, the enemy's active countermeasures, which are aimed at shooting down (losing) strike drones, were considered. This leads to the formation of an extra number of drones to reduce the risks of successfully completing the attack mission. To solve this problem, the indicators of the number of strike drones added were used. Increased strike potential is associated with increased risk of shooting down (losing) drones due to active countermeasures by the enemy.

5. Planning complex flight paths for a swarm of strike drones under active enemy countermeasures

Enemy countermeasures are considered using statistical data on drone attacks and corresponding enemy responses (including possible use of data from the DELTA situational awareness system). These statistical data make it possible to assess and calculate drone losses' risks. Modeling accuracy primarily depends on the reliability and timeliness of the data in the DELTA system.

While planning the movement of strike drones, a lot of attention is paid to the final stage of flight (the last mile), since the enemy can use new tactical actions and modern anti-drone means (mobile fire groups, air defense, electronic warfare, interceptor drones, etc.) to create a dense defense to protect targets. Therefore, the current task is to create confusing flight paths that complicate the enemy's actions to destroy the attacking drones. The use of confusing flight paths (e.g., zigzag, spiral, circular, and random deviation) between control navigation points will reduce the risk of drone damage but may increase drone flight time, which is not possible under existing constraints (e.g., fuel consumption, power supply, and batteries). Additionally, the advantage associated with the suddenness of the attack and the timeliness of the military mission may be lost.

Therefore, creating confusing flight paths is difficult, considering the compromise between the time (T) of the military mission, the risks of shooting down drones (R₁), and the risks of successfully hitting targets

(R₂). We formalise the representation and solution of the formed task using integer (Boolean) programming.

Assume that, for the final stage of the strike drone swarm's movement (the last mile), a complex approach trajectory to the enemy's targets must be formed. Then, when the strike drone moves from (j-1) to j control navigation point, it will use one of the possible flight trajectory options (snake, spiral, circle, stochastic deviation, etc.). Each e-th group (partial case, individual drone) of drones can use the k-th flight path option to confuse the enemy. Let us introduce a Boolean variable x_{jek} , which has the following values:

$$x_{jek} = \begin{cases} 1, & \text{if the } k\text{th trajectory option is selected} \\ & \text{for the } e\text{th group of attack drone swarm} \\ & \text{when flying from } (j-1) \\ & \text{to the } j\text{th navigation control point,} \\ 0, & \text{otherwise.} \end{cases} \quad (14)$$

Let's represent the indicators T, R₁, R₂ using a Boolean variable x_{jek} :

$$T = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n t_{jek} x_{jek}, \quad (15)$$

$$R_1 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{1jek} x_{jek}, \quad (16)$$

$$R_2 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{2jek} x_{jek}. \quad (17)$$

Here:

L is the number of control navigation points in the final flight stage of a swarm of strike drones;

n is the number of possible options for choosing the strike drone trajectory;

m is the number of groups in a swarm of attack drones;

t_{jek} is the travel time of the swarm's e-group between the (j-1) and j-th navigation points when selecting the k-th trajectory option;

r_{1jek} is the risk of shooting down an e-group of a drone swarm when the k-th flight path option is used;

r_{2jek} is the risk of successfully hitting the j-th target of the e-th group of strike drones when the k-th motion trajectory option is used.

In formulas (15) – (17), the concept of a group refers to both a single drone and multiple drones. The number is not explicitly considered because a group may consist of different drone types.

The following formulations of the optimization problem are possible, which is related to the flight path of a swarm of strike drones to enemy targets at the final stage of movement:

$$1. \min T, \quad T = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n t_{jek} X_{jek}, \quad (18)$$

with certain restrictions:

$$R_1 \leq R_1', \quad R_1 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{1jek} X_{jek}, \quad (19)$$

$$R_2 \leq R_2', \quad R_2 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{2jek} X_{jek},$$

where R_1' is acceptable risk value R_1 ;

R_2' is acceptable risk value R_2 ;

$$2. \min R_1, \quad R_1 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{1jek} X_{jek}, \quad (20)$$

with certain restrictions:

$$T \leq T', \quad T = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n t_{jek} X_{jek}, \quad (21)$$

$$R_2 \leq R_2', \quad R_2 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{2jek} X_{jek},$$

where T' is acceptable time value T .

$$3. \min R_2, \quad R_2 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{2jek} X_{jek}, \quad (22)$$

with certain restrictions:

$$T \leq T', \quad T = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n t_{jek} X_{jek}, \quad (23)$$

$$R_1 \leq R_1', \quad R_1 = \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{1jek} X_{jek}.$$

4. Formulation of multi-criteria problem.

Let's use the assessment of the significance of indicators (T, R_1, R_2) in the form of coefficients as follows:

$$(\alpha_T, \alpha_{R_1}, \alpha_{R_2}, \alpha_T + \alpha_{R_1} + \alpha_{R_2} = 1).$$

Meaning $\alpha_T, \alpha_{R_1}, \alpha_{R_2}$ can be added by military experts.

Let us form an additive convolution of normalized indicators in the form (T, R_1, R_2) as follows:

$$Q = \alpha_T \hat{T} + \alpha_{R_1} \hat{R}_1 + \alpha_{R_2} \hat{R}_2 \quad (24)$$

де $\hat{T}, \hat{R}_1, \hat{R}_2$ is прономовані (0÷1) значення показників (T, R_1, R_2):

$$\hat{T} = \frac{T - T^*}{T' - T^*}, \hat{R}_1 = \frac{R_1 - R_1^*}{R_1' - R_1^*}, \hat{R}_2 = \frac{R_2 - R_2^*}{R_2' - R_2^*} \quad (25)$$

where T^*, R_1^*, R_2^* is extreme indicator values.

It is necessary to find a compromise among the indicators (T, R_1, R_2) by:

$$\begin{aligned} \min Q, Q &= \alpha_T \hat{T} + \alpha_{R_1} \hat{R}_1 + \alpha_{R_2} \hat{R}_2 = \\ &= \frac{\alpha_T}{T' - T^*} \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n t_{jek} X_{jek} + \\ &+ \frac{\alpha_{R_1}}{R_1' - R_1^*} \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{1jek} X_{jek} + \\ &+ \frac{\alpha_{R_2}}{R_2' - R_2^*} \sum_{j=1}^L \sum_{e=1}^m \sum_{k=1}^n r_{2jek} X_{jek} - \\ &- \frac{\alpha_T T^*}{T' - T^*} - \frac{\alpha_{R_1} R_1^*}{R_1' - R_1^*} - \frac{\alpha_{R_2} R_2^*}{R_2' - R_2^*}. \end{aligned} \quad (26)$$

The following methods can be used to solve the formed integer (Boolean) programming problem:

- exhaustive search of options when there are relatively few;

- the branch and bound method is used when there are many possible options;

- random search method when there are a large number of options. It does not guarantee finding the extreme but allows you to improve the indicator's value relative to the search's starting point (for example, in percentages).

The methods are implemented in most modern mathematical software packages (e.g., MATLAB), which reduces calculation time.

Thus, this section addresses and solves the problem of planning the movement of strike drones to enemy targets in the final stage of flight (last mile). Considering the risk of drones being shot down (lost) due to active enemy countermeasures and the use of

anti-drone measures, a complex trajectory of strike drones to targets was formed from various components (snake, circle, spiral, random deviation, etc.). Using the integer (Boolean) programming method, a confusing trajectory of the strike drone swarm is formed, considering time indicators, the risk of drones being shot down, and the risk of successful completion of the attack mission. Individual indicators have been optimized and an optimization model has been created to find a compromise between time and risk indicators.

6. Development of an algorithm for forming flight routes for strike drones to enemy targets with minimal risk of drone destruction

The rapid dynamics of changing circumstances on the battlefield in modern warfare do not allow for the full implementation of the initial attack mission plan using a swarm of strike drones. Active countermeasures by the enemy, aimed at protecting their targets, force the re-planning of strike drone flights, considering significant changes in military circumstances, to reduce the risk of drone destruction or loss. Therefore, there is an urgent need to develop a method for forming flight routes under increased enemy risk, enabling the rational movement of strike drones to successfully complete a military mission. Existing routing methods (for example, the well-known Dijkstra algorithm and its modifications [32]) minimize flight time without considering risks, which is why they are used. Note that existing routing algorithms are based on analytical calculations using a graph representation of possible route trajectories. Modern simulation modeling methods, which explicitly represent time and its changes, allow simulating movement with various possible obstacles. Therefore, an original algorithm for routing strike drones to enemy targets was developed, which uses simulation modeling and has the following advantages over analytical methods:

1. Ability to quickly respond to changing military conditions on the battlefield by creating a new flight route.
2. Ability to conduct parallel flight simulation of multiple strike drones in a swarm.
3. Form competitive routes, both in terms of time and risk, rejecting unpromising routes.
4. Use risk values to form detours around dangerous local areas where enemy anti-drone weapons are located.
5. It can generate flight routes for a swarm of strike drones with minimal time and risk.
6. It can quickly replan the flight route of strike drones, depending on the battlefield circumstances.

The Any Logic agent platform [33] was used in the developed simulation modelling algorithm.

The modelling algorithm for searching for rational flight routes for a swarm of strike drones to enemy targets is presented in the form of a sequence of steps:

Step 1. Formation of a map of air conditions on the battlefield in the form of a set (M) of control navigation points (including drone launch points and enemy targets). Each navigation point is associated with a local area in which enemy anti-drone measures (ADM) may be formed over time.

Step 2. The characteristics of each j -th ($j = \overline{1, N}$) and its local zone (LZ) are set for the initial simulation moment:

- risk (R_j), which depends on the use of military equipment (mobile fire groups, air defence, electronic warfare, interceptor drones, etc.) by the enemy;
- size of the memory in which the software is located.

The risk R_j depends on the effectiveness of the enemy countermeasures. It can be evaluated using statistical data on enemy counteractions conducted through various means, collected and analyzed within the DELTA system.

Step 3. The launch of a swarm of strike drones is initiated from the initial navigation launch point (multiple points may be used).

Furthermore, in the description of the algorithm, strike drones will be represented as “entries” in the existing terminology of simulation modelling to simulate flight.

Step 4. Requests (drones) move to neighboring navigation points and mark them (this means that they were the first to reach those points).

Step 5. After the application has reached each navigation point, copies of applications (clones) are formed and distributed, which then move on to the next neighboring point (from point $(j-1)$ to point j).

Step 6. If an application (clone) reaches a point that has already been marked by a previous application (clone), the movement of this application (clone) is stopped, and it is destroyed. This is because this application is not competitive in terms of travel time, as it has a longer travel time than that of the previous application (clone) that arrived earlier.

Next, steps 4, 5, and 6 are repeated until the navigation point where the target is located is reached.

Step 7. A flight route for the strike drone swarm is created by forming a trajectory in the form of a set of navigation points from enemy targets to the strike drones’ initial launch point.

A schematic representation was not used to describe the algorithm, as it was necessary to provide a more detailed explanation of each step.

The algorithm allows forming a route for a swarm of strike drones to enemy targets with minimal time (T_{\min}) in the absence of active enemy counteraction.

The first modification to the algorithm was introduced, which considers the risks (R_j) arising from active enemy counteraction and is significant for disrupting the movement of strike drones to enemy targets.

In this case, point 2 of the developed algorithm is used, which provides the characteristics of navigation points and their LZs obtained through battlefield and military assessment reconnaissance. Therefore, we record the risk values (R_j) of the destruction or loss of strike drones for all navigation points and their LZs. We set a risk threshold that characterizes the unacceptable risk for passing through point j and LZ by a strike drone ($R_j \geq R'_j$). Next, we construct a reduced set of navigation points to form a swarm of strike drones. We use the developed algorithm to generate strike-drone swarm routes, accounting for enemy counteraction risks. Simultaneously, when forming the minimum flight route of the strike drone swarm in terms of time, we have the opportunity to form the total risk value of reaching the enemy's targets ($R = \sum_{e=1}^L R_e$, where L – number of e-navigation points used to generate a route).

Thus, the first modification of the algorithm has been developed, which allows to form a minimum flight route in terms of time, which is relatively safe, with a summed value of the risk of reaching enemy targets by a swarm of strike drones.

Let us consider the second modification of the algorithm, in which the strike drones' route is formed to minimize the risk of reaching enemy targets (R_{\min}). In this case, using risk as the main factor in simulation modeling is necessary. Therefore, instead of the system time value (T) and its change, the risk value (R) arising from active enemy countermeasures will be used in simulation modelling. All simulation modeling actions (steps 1-7) are performed in terms of risk rather than time. Thus, a relatively safe route for strike drones to enemy targets is formed with a minimum risk value (R_{\min}). It is possible to form the flight time value of strike drones, which is summed up and formed as

$T = \sum_{i=1}^F T_j$ for those 1st navigation points used in the drone flight path.

A third modification of the algorithm was developed using the complex criterion value as the main factor in simulation modeling.

$$Q = \alpha_T \hat{T} + \alpha_R \hat{R}.$$

To do this, it is necessary to first set the importance of the indicators. T, R ($\alpha_T, \alpha_R, \alpha_T + \alpha_R = 1$). Next, the values of T and R must be normalized as follows:

$$\hat{T}_j = \frac{T_j - T_{j-1}}{\sum_{j=1}^P (T_j - T_{j-1})}, \quad (27)$$

$$\hat{R}_j = \frac{R_j}{\sum_{j=1}^P R_j}. \quad (28)$$

Significant changes in battlefield circumstances may require an update (replanning) of the initial flight plan for the strike drone swarm. The navigation points used as the starting points from which requests (drones) are initiated and formed and their distribution to enemy targets is carried out using the developed algorithm are those that have been reached at the current moment in time or those that will be reached in the near future.

A distinctive feature of the developed algorithm (and its modifications) is its ability to perform calculations at both the ground control station and onboard the UAV. Furthermore, the flight trajectories can be transformed into flight tasks for strike drones using existing application systems (e.g., Mission Control).

Thus, this section addresses and solves the urgent task of forming strike drone movement in conditions of active enemy counteraction. An original algorithm has been created using simulation modeling, which allows the formation of rational flight routes for strike drones and has advantages over existing analytical routing methods.

Using the developed algorithm, the trajectory of a swarm of strike drones can be generated to be both time-minimal and risk-minimal in reaching enemy targets. The algorithm enables operational correction (replanning) of strike drone flight plans based on current circumstances and battlefield changes.

7. Imitation multi-agent model for simulating a massive attack using a strike drone swarm

A simulation model for planning and executing strike drone missions was implemented in AnyLogic using a multi-agent architecture. The main agent, which acts as the control and coordination environment, is the central component of the system. It contains all agent populations and generates scenarios, builds routes, launches missions, and collects simulation results. The integration of geoinformation data, UAV parameters,

the location of enemy air defense/electronic warfare assets, and the general logic of drone behavior is carried out in the main agent.

Each mission is modeled by a separate Mission agent, which combines a group/swarm of drones, a list of waypoints, and information about the final target. The mission contains a sequence of WayPoint objects and navigation points that determine the flight path: the starting point, intermediate maneuvering positions, and the final point of attack or reconnaissance. Main forms a multi-segment route in the form of a GIS curve based on WayPoint, along which the drones move.

Agent Drone represents a separate UAV that performs a mission according to specified parameters and launch mode. The drone moves along the route, is checked for exceeding the flight duration, for entering the areas of air defense/electronic warfare systems, and also changes its status depending on the course of the simulation (swarm separation, successful completion, destruction, or return). The drone's characteristics are inherited from the UAV agent, which serves as a reference for UAV types and contains information on their tactical and technical parameters (e.g., speed, payload, and range).

Threats from the enemy are represented by Radar agents that simulate air defense stations or electronic warfare systems. Each Radar has a geospatial location and coverage radius within which drones can be detected and destroyed with a certain probability. When the kinetic interception model is used, the Radar can initiate the launch of a Missile agent, which pursues and strikes the attack drone.

Target agents represent enemy targets for destruction, which include combat value, probability of successful destruction, importance to the operation, and

other parameters. The mission is directly linked to the target, allowing the model to assess the damage caused during the attack.

A separate functional module, CriteriaComparison, is responsible for calculating the weighting coefficients of target priority using the method described in this paper, which allows the planner to automatically determine the most important targets to be hit under given conditions.

In general, the proposed agent structure provides natural modeling of complex interactions between participants in the operation: mission routes are formed considering the characteristics of UAVs, targets, and threats; drones autonomously perform flight logic, swarm separation, etc.; air defense/electronic warfare means that they react to their appearance; and mission results are aggregated for further analysis of effectiveness and risks. This approach allows modeling scenarios of varying complexity—from single operations to coordinated attacks by a swarm of UAVs in a dynamic combat environment.

Fig. 1 shows a block diagram of a multi-agent model for simulating strike drone movement under active enemy countermeasures.

The results of simulating the movement of strike drones towards targets under active enemy countermeasures are as follows:

- flight route(s) set and modeled using a developed simulation model;
- trajectory and movement time of a swarm of strike drones in the absence of significant countermeasures;
- minimum trajectory of strike drones in the absence of enemy anti-drone actions in terms of time;

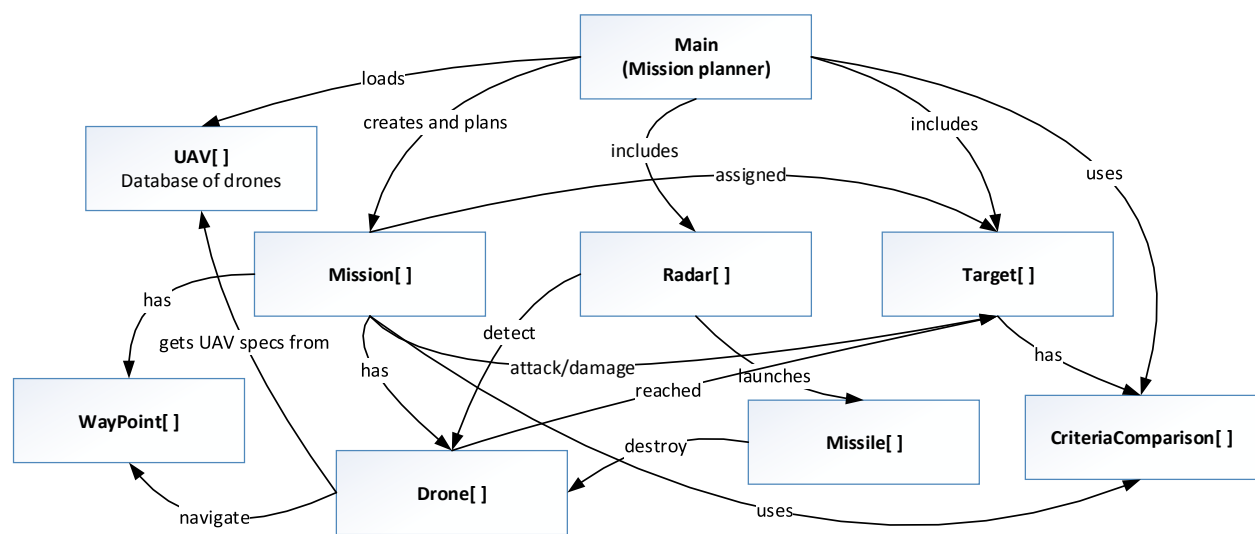


Fig. 1. Agent-based architecture of the UAV mission planning model

- the minimum trajectory of the strike drones in terms of time in the absence of enemy counter-drone actions;
- the minimum trajectory of the strike drones in terms of the risk of enemy counter-drone actions;
- a rational flight route for strike drones using time and risk indicators.

It is possible to form the risk value (R_i) using a random generator. In this case, it is necessary to perform multiple simulations and then statistically average the results.

Thus, this section addresses the task of creating a simulation model for planning and executing strike-drone missions under active enemy counteraction. Various scenarios of possible strike drone movements are considered (without risks, with risks, with a search for minimum travel time, with a search for minimum risk of movement to the target, formation of a rational route considering time and risks, re-planning of movement due to changing circumstances on the battlefield). The use of the developed multi-agent model for planning the flight of a swarm of strike drones for an attack mission enables consideration of real battlefield conditions and the proactive mitigation of threats posed by active enemy actions.

8. Example of modeling an attack mission by strike drones in active enemy counteraction conditions

A series of simulation experiments was performed in the AnyLogic environment to demonstrate the operation of the proposed model complex. The main purpose of the examples is to evaluate the effectiveness of various tactical approaches to breaking through enemy air defense and electronic warfare zones during UAV swarm strike missions. This study considers two typical scenarios: swarm separation and flanking attack. Both scenarios were modeled in conditions of active enemy

counteraction using detected and probable air defence system positions.

Possible scenarios of offensive missions were examined in detail and formalised in [34].

1. Swarm separation scenario. In the first example (Figs. 2 and 3), a swarm of strike drones is divided into several groups, each of which heads to specific intermediate points along the route to create confusing trajectories and reduce the likelihood of the entire group being simultaneously destroyed by air defense systems. The route for each subgroup contained a large number of maneuvering points, which made it possible to form complex, “non-linear” trajectories that make it difficult for the enemy to predict drone movement.

The map clearly shows how drones move through several branching paths, avoiding air defense zones. Some of the devices are lost, but the rest successfully reach their targets. The system automatically calculates the percentage of target damage and drone losses and generates a table with the following statistical parameters of the routes: number of maneuvering points, route length, number of drones in the mission, flight speed, and time in the air.

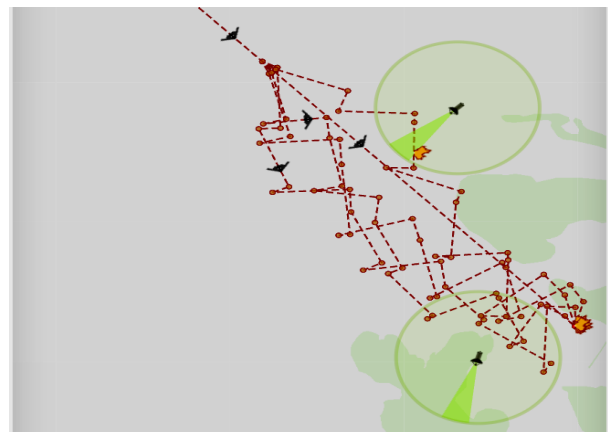


Fig. 2. Mission planning with drone swarm separation

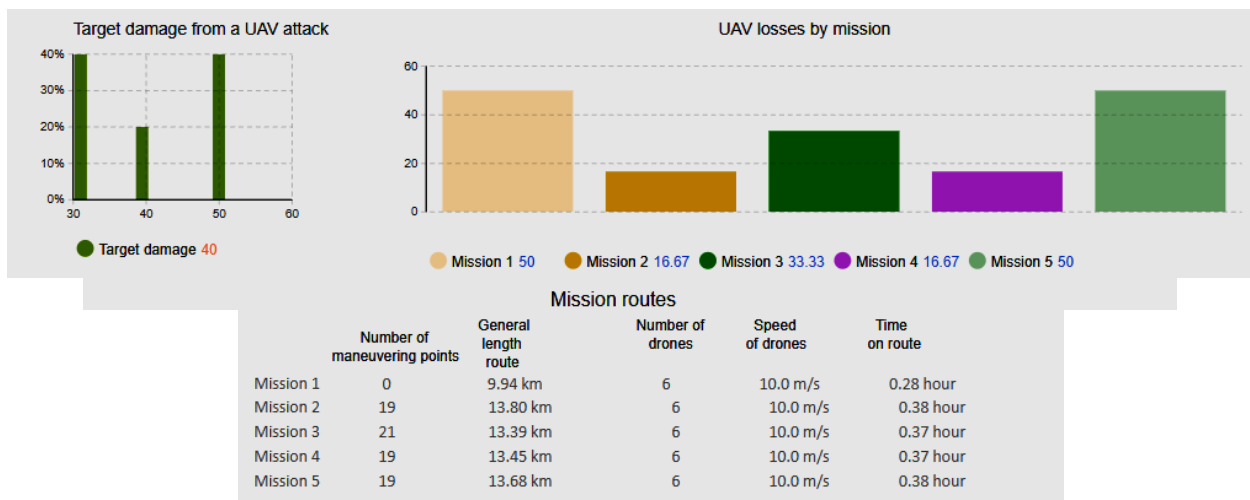


Fig. 3. Results of modeling the separation of a swarm of drones

All missions have different launch points and targets.

The simulation results showed that the swarm separation strategy reduces risk concentration and increases the probability of successful target engagement. Simultaneously, due to the increased complexity of the routes and flight duration, the partial loss rate of UAVs increases.

2. Flank attack scenario. The second scenario (Figs. 4 and 5) implements flank breakthrough tactics, in which the main group of drones maneuvers on the periphery of the air defense zone, and the strike is delivered at an atypical angle rather than a straight trajectory. This makes the enemy's countermeasures less effective because the enemy's observation and firepower are focused primarily on the attack's frontal direction.

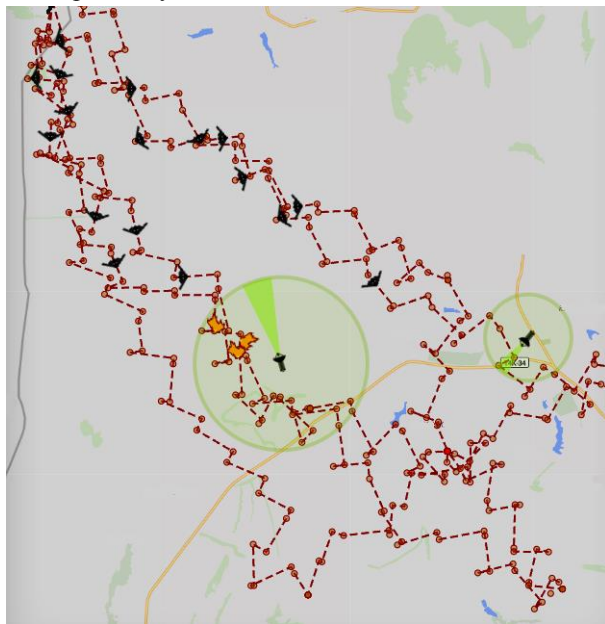


Fig. 4. Planning a flanking drone strike mission

The flanking approach provides significantly longer routes and more maneuvering points than the swarm separation scenario, but it also reduces the intensity of drone strikes in areas with dense air defense. The results show that the percentage of losses is lower and the degree of damage to the target is higher. In particular, in the given example, the target damage reached 52%, which is a better indicator than in the previous scenario.

The mission parameters table shows a significant increase in the number of maneuver points (up to 50 or more) and a longer flight time, which is a direct consequence of a more complex trajectory and a longer overall route length.

Analysis of the two scenarios allows us to identify their key advantages and limitations.

Splitting the swarm increases the operation's resilience to massive damage but increases losses due to a greater number of entries into risk zones and shorter maneuvering distances.

A flanking strike reduces drone damage and increases target strike efficiency, but requires more complex planning and a longer mission duration.

Modeling has confirmed that the developed methods for planning the movement of strike drone swarms, in conditions of active enemy counteraction, provide flexible trajectory changes and the use of non-standard attack directions, which significantly increase the chances of breaking through enemy air defense zones. The proposed methods and models allow not only to assess the probability of success in various tactical conditions, but also to optimize route design to reduce expected losses.

The obtained results demonstrate the practical value of the created simulation model for analyzing and selecting effective tactics for the massive use of strike drones in combat conditions with active enemy countermeasures.

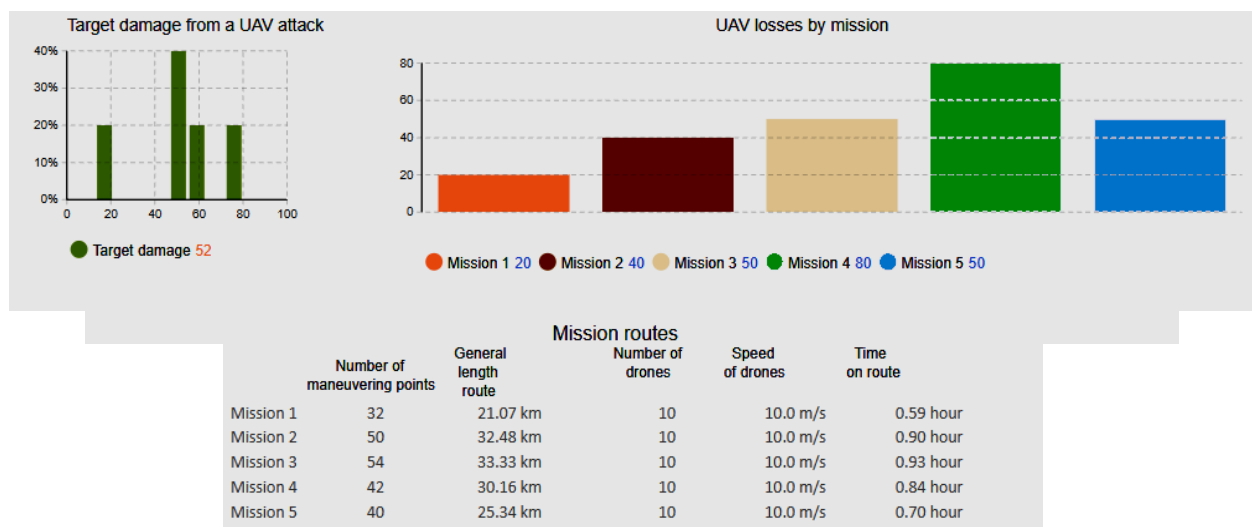


Fig. 5. Results of modeling the separation of a swarm of drones

9. Discussion

The turbulence of modern warfare, driven by the use of innovative tactical and technological solutions, leads the enemy to deploy new defensive measures against critical objects (targets) using anti-drone capabilities (e.g., anti-aircraft drones, interceptor drones, and laser weapons). This complicates the execution of a successful attack mission using a swarm of strike drones. This study provides a systematic analysis of the planning of an attack mission using strike drones in the context of active enemy counteraction and dynamic changes in military circumstances on the battlefield.

Selecting relevant enemy targets is a complex task that involves assessing the impact of their destruction on the enemy's combat capabilities. The risks of shooting down (losing) strike drones due to active enemy countermeasures were considered when developing models for planning an attack mission. Difficulties arise due to limited capabilities to create the necessary strike potential to destroy the entire set of enemy targets. Therefore, a subset of relevant targets was formed using lexicographic ordering of options and values of key indicators of enemy targets, which were presented in both quantitative and qualitative metrics.

The increased risk of strike drones being hit (lost), especially when approaching targets, with the enemy using a wide range of anti-drone weapons, makes it necessary to increase the pre-planned strike potential (increase the number of drones) as a possible preventive countermeasure against the enemy. Depending on the significance of the targets and the impact of their destruction on the enemy's combat potential, the required number of strike drones is selected, while accounting for the risk of being shot down (losses). The complex circumstances created by the enemy to counter the movement of strike drones force the formation of confusing trajectories for strike drones (e.g., zigzag, spiral, circle, random deviation, swarm separation, and flanking strike). This is especially important for the final attack stage (the last mile). Therefore, an analysis and selection of a set of components of the flight trajectory of strike drones was carried out using integer (Boolean) programming, which reduces the risks of drones' shooting down (losses).

The dynamics of changing situations on the battlefield necessitated revising the initial plan for the flight of strike drones and re-planning the attack mission. Therefore, an original routing algorithm was developed, which differs favorably from existing analytical methods (e.g., Dijkstra's algorithm), as it is based on simulation modeling of the movement of a swarm of strike drones on a given time scale. The algorithm is based on the ability to multiply requests (clones) and

select competitive requests whose movement has been minimized over time.

Much attention is paid to the enemy's ability to destroy strike drones in flight using modern mobile fire groups, air defense, and electronic warfare. Therefore, a search was conducted for the minimum flight route risk for attack drones to successfully complete their attack mission. Modeling and search for a relatively safe route for attack drones to enemy targets were carried out by changing the main simulation modeling factor (system time) to a risk factor.

A multi-agent model was created in AnyLogic to simulate the movement of strike drones under active enemy counteraction.

An illustrated example of the application of the developed methods and models in the strike drone mission planner software is provided, with the implementation of various scenarios for forming a drone swarm and searching for relatively safe routes for strike drones to reach their targets under enemy counteraction conditions.

The following research methodology is proposed:

- systematic analysis and identification of multiple relevant enemy targets using a swarm of strike drones. This considers the limited capabilities for creating the swarm's necessary strike potential;
- calculation of the number of strike drones in an attack mission, considering the enemy's capabilities to increase countermeasures;
- formation of a complex flight path for a swarm of strike drones to enemy targets, using confusing components to reduce the risk of shooting down (losses) the attacking drones;
- creation of a relatively safe, low-risk route for strike drones using a simulation-based original routing algorithm;
- simulation of strike drone movement under active enemy countermeasure conditions using multi-agent modeling;
- creation of an illustrative example to justify the effectiveness of the proposed approach in planning an attack mission using a swarm of strike drones under active enemy counteraction conditions.

The proposed approach is relevant due to the need for scientific justification of an attack mission plan involving a swarm of strike drones in dynamic battlefield environments and amid active enemy countermeasures.

The developed set of models simulates an attack mission using a swarm of strike drones to form a plan for military operations on the battlefield.

This allows us to conclude that the proposed approach is timely and effective for the successful execution of military operations on the battlefield using a swarm of attack drones.

Future research will focus on improving the applied information technology for modeling an attack mission using a swarm of strike drones under active enemy counteraction, thereby contributing to the success of planned military operations on the battlefield.

10. Conclusions

This study substantiates a plan for offensive actions using a swarm of strike drones in conditions of active enemy counteraction, including the following:

- selecting a significant subset of relevant targets, the destruction of which will reduce the combat potential of the enemy and disrupt the logistics of supplying military equipment to the battlefield;
- justify an additional number of strike drones as a preventive measure against increased enemy countermeasures to destroy drones;
- form complex (confusing) trajectories for strike drones to enemy targets under the risk of destruction (loss);
- to ensure the correction (replanning) of the flight route of a swarm of strike drones under dynamic changes in battlefield circumstances;
- simulate the movement of drones under various enemy counteraction scenarios based on agent-based simulation modeling.

The scientific innovation of the proposed approach lies in the justification of the plan for conducting an offensive mission using strike drones in the face of active enemy counteraction and dynamic battlefield conditions, supported by a set of analytical and simulation models.

Thus, the main conclusion (the main contribution) of the study can be made as follows:

The proposed set of models and information modeling technology allows justifying the plan for conducting an attack mission using a swarm of strike drones, namely: to select a subset of relevant targets that is significant for restraining the enemy's military actions, to form the required number of drones, in conditions where the enemy uses modern anti-drone means, to form a complex trajectory of drone movement to reduce the risk of them being shot down, which will ensure the successful completion of combat tasks on the battlefield.

This will ensure the success of the military mission, which integrates combat operations on the battlefield and air operations, using massive attacks on enemy targets with a swarm of strike drones.

Contribution of authors: system analysis for planning offensive missions with strike drones in conditions of active enemy counteraction – **Oleg Fedorovich**; methods for forming flight routes for strike drones and a simulation model for planning and simulating drone

missions – **Oleksandr Prokhorov**; assessment of multiple strike drones for conducting an attack – **Dmytro Krytskyi**; optimization models for modeling an attack mission – **Olga Malyeyeva**; conducting calculations of experiments on models – **Oleksandr Leshchenko**; justification of multiple military actions on the battlefield using strike drones – **Roman Trishch**.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Authors **Oleg Fedorovich**, **Oleksandr Prokhorov** and **Oleksandr Leshchenko** is a member of the Editorial Board of this journal. They did not involved in the peer review, handling, or decision-making process for this manuscript.

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Data availability

The manuscript has no associated data.

Use of Artificial Intelligence

The authors confirm that they did not use artificial intelligence methods while creating the presented work.

All authors have read and approved the published version of this manuscript.

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МОДЕЛЮВАННЯ АТАКУЮЧОЇ МІСІЇ УДАРНИХ ДРОНІВ, В УМОВАХ АКТИВНОЇ ПРОТИДІЇ ПРОТИВНИКА

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Стрімке зростання інновацій в сучасній війні призвели до необхідності, при плануванні атакуючих місій, з використанням ударних дронів, враховувати можливості противника щодо створення оборони сучасними протидроновими засобами. Тому, **актуальне** проведення дослідження превентивних дій, при плануванні масованої атаки, які спрямовані на подолання перешкод руху ударних дронів до цілей противника. **Предметом дослідження** публікації є розробка аналітичних та імітаційної моделей, які дозволять планувати атаку з мінімізацією ризиків від протидронових дій противника. **Метою** дослідження є створення комплексу математичних та імітаційної моделей, за допомогою яких можна планувати рух рою ударних дронів, в умовах активної протидії противника. **Завдання**, які необхідно вирішити: системно проаналізувати дії щодо планування атакуючої місії, в умовах динамічних змін обставин на полі бою; вибрати підмножину із множини актуальних цілей противника для проведення атаки; створити потрібну кількість ударних дронів для атаки, в умовах обмежених можливостей; створити заплутані траєкторії руху ударних дронів, для успішного ураження цілей противника; розробити алгоритм формування маршруту польоту, з мінімальним ризиком збиття (втрат) дронів; створити імітаційну модель для симуляції руху рою ударних дронів до цілей, в умовах активних протидій противника. Використані **математичні методи та моделі**: системний аналіз, для створення логістичної послідовності дій щодо проведення атаки ударними дронами; якісне та кількісне оцінювання характеристик можливих цілей противника; лексикографічне впорядкування варіантів для вибору підмножини актуальних цілей противника; цілочисельна (булева) оптимізація для розрахунку кількості ударних дронів, які будуть задіяні в атаці; агентне імітаційне моделювання для формування руху ударних дронів, в умовах протидій противника. Отримані наступні **результати**: запропоноване системне представлення планування атакуючої місії ударними дронами, в умовах динамічної зміни обставин на полі бою; обґрунтовано вибір підмножини актуальних цілей для проведення масованої атаки; розрахована потрібна кількість атакуючих дронів, в умовах обмежених можливостей; розроблено алгоритм для створення маршруту руху ударних дронів, з мінімальним значенням ризиків польоту; створена агентна модель симуляції польоту рою ударних дронів для різних сценаріїв активної протидії проривника. **Висновки**: результати проведеного дослідження дозволяють науково обґрунтувати створення плану щодо проведення атакуючої місії роєм ударних дронів, в умовах активної протидії противника, що сприяє інтегруванню бойових дій у повітрі та на полі бою та дає можливість успішного виконання запланованої військової операції. **Новизна** запропонованого підходу полягає у науковому обґрунтуванні плану проведення атакуючої місії, з використанням ударних

дронів, в умовах активної протидії противника та динамічних змін обставин на полі бою, за рахунок розробленого комплексу оригінальних та нових аналітичних та імітаційної моделей.

Ключові слова: рій ударних дронів; атакуюча місія; актуальні цілі противника; мінімізація ризиків руху дронів; оптимізація кількості атакуючих дронів; імітаційне мультиагентне моделювання руху ударних дронів.

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