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MODELING OF STRIKE DRONE MISSIONS FOR CONDUCTING WAVE ATTACKS IN CONDITIONS OF ENEMY ANTI-DRONE ACTIONS

The actual problem of studying military logistics actions to form missions of a swarm of attack drones for conducting massive attacks on enemy targets is formed and solved. The research is aimed at planning military attacks with drones to provide for establishing military parity of forces in a military conflict zone. Therefore, the actual topic of the proposed publication, which explores the sequence of military logistics actions for planning and implementing wave attacks to inflict maximum damage on the enemy, is relevant. The goal of this publication is to create a set of mathematical, simulation and agent-based models that can be used to study and plan attack missions by waves of swarms of attack drones. This article analyzes the existing problems of using a new innovative technological tool of warfare in the form of a swarm of attack drones. A systematic analysis of military logistics for conducting massive attacks with strike drones is carried out. A set of strategies for using a swarm of drones on the battlefield is formed. Possible actions related to launching drones, forming a swarm in flight, and dividing the swarm into groups with their movement to separate enemy targets are considered. Risks of enemy military threats (use of electronic warfare, anti-drone warfare, etc.) that affect the formation of routes and the possible destruction of a portion of attack drones on approach to targets are taken into account. The swarm is rationally divided into groups in flight, considering the combat potential required to defeat the enemy's current targets. A sequence of drone swarm waves is formed depending on the level of target damage (partial damage, complete damage). When planning each wave of the drone flight, one of the proposed strategies is used. Much attention is paid to the formation of flight routes for attack drones to ensure the suddenness of a massive attack despite enemy military threats. An algorithm for generating the shortest flight route in time despite enemy anti-drone operations has been developed. A map of the air situation on the battlefield with a set of separate local zones that have different values of threat risks is formed. The route is planned considering the military risks of each local zone. A simulation model was created to study the movement of attack drones to enemy targets in time. An agent-based model is being developed to plan military logistics actions for conducting wave attacks on enemy targets using swarms and groups of attack drones. An illustrated example of planning the flight routes of a swarm of attack drones is presented, taking into account the risks of military threats. The scientific innovation of the study is related to the solution of the actual scientific and applied problem of planning the missions of a swarm of attack drones to ensure successful operational and tactical actions on the battlefield. The results of the research should be used by the military to plan and conduct attacks on enemy targets in the form of waves of swarms of attack drones.

Keywords: *swarm of strike drones; planning of wave attack missions; combat potential of drones; optimal flight route; simulation model; agent-based model.*

1. Introduction

In the context of modern hybrid wars, a swarm of attack drones is an innovative element that allows for effective combat operations [1, 2]. However, the enemy's use of anti-drone weapons reduces the swarm's combat potential when approaching targets [3, 4]. Therefore, the task arises of conducting several launches of a swarm of drones in the form of waves to provide the planned defeat of enemy targets [5, 6]. To do this, it is necessary to develop strategies for wave attacks using a swarm of attack drones [7, 8]. It is necessary to take into account the types and number of drones in a swarm to form the combat potential necessary to defeat targets, as well as to choose rational flight paths in the context of threats [9, 10]. Actions to form a swarm of drones, plan swarm waves, and control flight are carried out in the conditions of enemy anti-drone actions (electronic warfare and anti-drone warfare) [11, 12]. Taking into account the risks of threats when planning a massive attack using a swarm of drones is a difficult task, which is associated with the actions of the enemy to destroy drones when approaching targets.

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Taking into account the above, we can conclude that it is relevant to conduct a study on the formation of strategies and planning of wave attacks using a swarm of attack drones.

1.1. Motivation

Forming a swarm of drones is a difficult task because it is necessary to take into account the possible types of drones that will be used in the swarm to conduct an attack with their tactical and technical characteristics (flight range, payload, etc.). When planning a wave attack, it is necessary to form a set of actual enemy targets that can be hit by a swarm of drones, taking into account the limited capabilities of drones [13, 14]. Then, with the help of intelligence, it is necessary to assess the military situation on the battlefield, as well as to calculate the necessary combat potential of drones to hit targets. After the attack, it is necessary to determine the degree of damage to the targets to form new waves of swarms [15, 16].

When creating flight waves, tasks arise to control the swarm and divide the swarm into groups that will move toward selected enemy targets despite intensified anti-aircraft operations.

Therefore it is important to solve the problem of planning the number of waves of a swarm of attack drones for their effective use on the battlefield [17, 18].

1.2. State of the Art and problem statement

There are many problems associated with the use of drone swarms on the battlefield. Some problems are being solved, but there are new problems that require research:

1. Formation of a Multitude of Strategies for Conducting Wave Attacks by a Swarm of Strike Drones [19, 20].
2. Creating a swarm of attack drones from different types of UAVs [21, 22].
3. Formation of the necessary combat capability of a swarm of drones to defeat enemy targets [23, 24].
4. Limited capabilities of drones in attack operations (flight range, combat potential, size of the affected area, availability of anti-drone weapons, etc.) [25, 26].
5. Formation of drone swarm groups to defeat isolated enemy targets [27, 28].
6. Planning flight routes for a swarm of drones despite military threats [29, 30].
7. Possible change of flight route due to new military situation in real time [31].
8. Coordinating a swarm of drones and creating a swarm group management system [32].

This is an incomplete list of problems that continue to grow in the context of hybrid war, which indicates the relevance of using an innovative technological instrument in the form of waves of swarms of attack drones to conduct effective operational and tactical actions on the battlefield.

This work uses a systematic analysis of strike drone missions, which requires a structural and dynamic representation of the planning process. Structural representation (swarm composition, multiple drone groups, flight paths, etc.), which has a set of possible options. To study and select rational ones, taking into account indicators (time, flight range, swarm combat load, risks, etc.), integer (Boolean) programming was used, which has experience in research in many applied fields, where a set of alternative options is formed and the necessary ones are selected.

For dynamic analysis, a modern method of simulation agent modeling was used, which allows, in detail, on a given time scale, to investigate and plan flight trajectories, the division of the swarm into groups, the appearance and impact of enemy anti-drone actions, etc.

This work presents possible solutions to the above-mentioned urgent problems, namely:

- a set of strategies for wave attacks by strike drones is substantiated;
- modeling of the creation of drone swarms and swarm groups is carried out;
- the formation of the combat potential of the swarm is carried out, considering the limited capabilities of the drones;
- optimization of drone flight paths is carried out, considering risks and flight time;
- a model is created for the analysis of dynamic events in drone flight (change of routes, emergence of military threats, etc.).

1.3. Objectives and methodology

There is a contradiction between the need to plan effective combat operations using a swarm of attack drones and the imperfection of existing methods, models and information technologies that do not allow for the full planning of effective massed attacks using waves of swarms of attack drones.

The goal of this study is to create a set of mathematical, simulation, and agent-based models that can be used to plan drone swarm missions to enemy targets.

In accordance with the research goal, the following tasks need to be solved:

1. To form a set of strategies for wave attacks with strike drones.
2. To rationally divide a swarm of drones into groups to conduct attack actions against individual enemy targets.

3. Form a set of waves of a swarm of attack drones depending on the level of damage to the enemy targets.

4. Form a flight mission for a swarm of attack drones.

5. Develop a multi-agent model for planning the flight routes of a swarm of attack drones.

6. Provide an illustrated example of modeling attack actions using a swarm of attack drones.

The article is organized as follows.

Section 2 is devoted to a systematic analysis of the multitude of strategies for planning attack missions using waves of swarms of attack drones.

Section 3 is related to the creation of an optimization model for the rational division of a swarm of attack drones into groups, which ensures maximum damage to the enemy, up to the complete defeat of the targets.

Section 4 is devoted to the study of wave attacks using strike drones. The combat potential of drones, the degree of damage to targets, and possible enemy counter-drone actions were evaluated.

Section 5 is devoted to the logistical actions for planning an attack mission using a swarm of attack drones. An algorithm for routing drone flight despite possible military threats from the enemy is presented.

Section 6 is related to the development of a multi-agent model for studying the flight of attack drones in time and on the map despite enemy anti-drone operations.

Section 7 illustrates, using an example, the effectiveness of the proposed approach for planning an attack mission using waves of swarms of attack drones.

Section 8 contains 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 in the special situation of the country.

Section 9 concludes the article by summarizing the conclusions, giving a perspective for further research and development of applied information technology for managing the missions of attack drones on the battlefield.

2. Formation of a set of strategies for wave attacks with strike drones

The formation of a set of strategies for wave attacks by combat drones depends on the following factors [33, 34]:

1. The presence of a set of actual enemy targets that require the necessary combat capabilities to defeat them, considering the capabilities of individual drones.

2. The launch of attack drones can be carried out from several locations rather than one, which leads to different lengths and times of drone flight routes to targets.

3. The division of a swarm of drones into groups to defeat enemy targets can be carried out not at one navigation point of flight, but at several points.

4. The number of waves of attacking drones depends on the tasks of the military leadership (to completely or partially destroy enemy targets, to cause damage to the enemy).

5. The priority of the targets affects the direction of movement of the shock waves of the combat drones.

6. The presence of risks of military threats (pro-terrorist actions, electronic warfare activity, etc.), which affects the number of combat drones in the swarm, as well as the number of waves of massive attacks on enemy targets.

Thus, it is necessary to initially consider the types of drones that can be used to perform the task. There are quite a few features for classification, one of them is the principle of division by the functional task that they perform (Fig. 1). When performing combat missions, the most suitable feature is the complex feature of dividing drones into classes based on mass and dimensional characteristics, which actually determine one of the main parameters of the drone - the maximum payload that the drone can carry. This indicator will be one of the main ones when choosing specific drones to perform a task, since the payload mass required to perform a task is determined before planning the mission. It is also necessary to understand the distances at which the drones in the swarm will interact (if the distances are minimal, then copter-type drones will be suitable for performing the task, in the case of medium and large distances within the swarm - aircraft and helicopter types).

Let us devise a set of strategies that can be used when planning attacking actions by waves of swarms of attack drones on the battlefield:

1) A swarm of drones is formed and launched from one place (A) and attacks one place where the enemy targets are concentrated (B) (Fig. 2).

This strategy is already being used on the battlefield. Controlling and coordinating drones in a swarm is not as difficult as the following strategies.

2) The strategy of launching a swarm of drones from one location (A) and conducting attacks on targets in different locations (B_1, B_2, ..., B_N) (Fig. 3).

In this case, when launching drones, groups are formed, their number corresponding to the number of targets (N). For this strategy, the attack drones are controlled at the group level.

3) The strategy of launching drones from different locations (A_1, A_2, ..., A_M) to conduct a massive attack at one location (B) with many concentrated enemy targets (Fig. 4).

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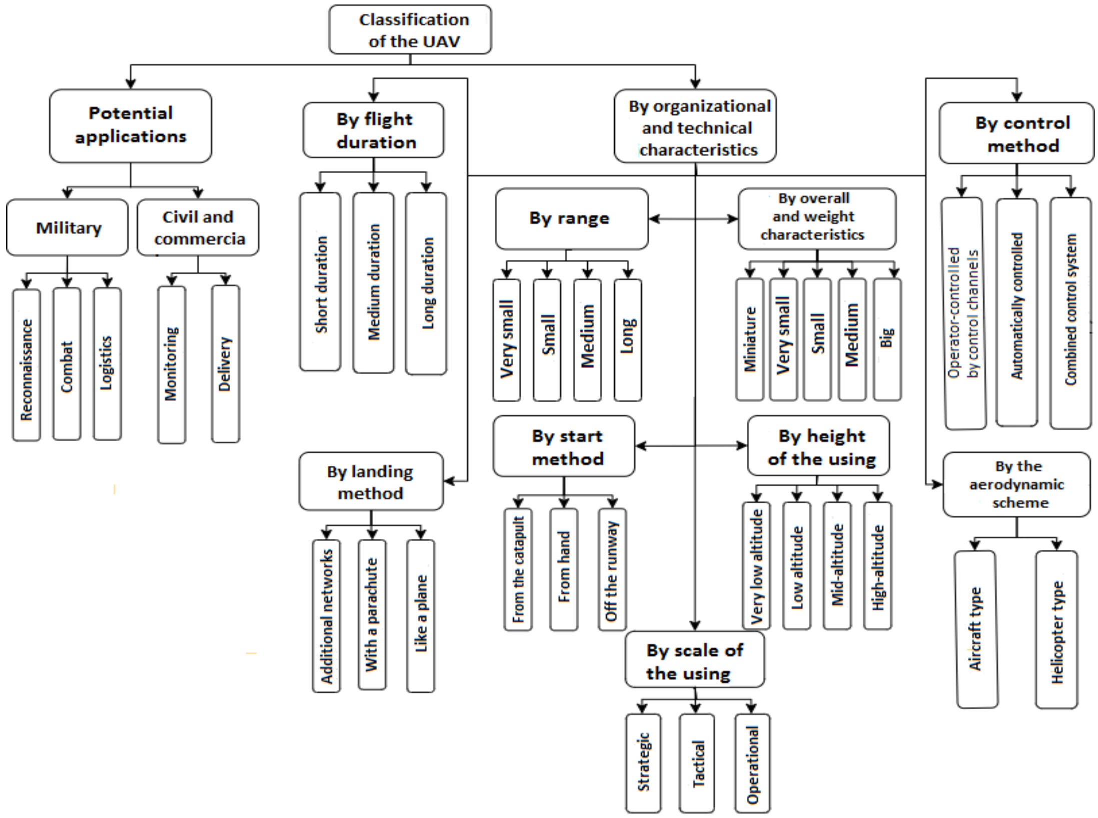

Figure 1. Classification of the UAV

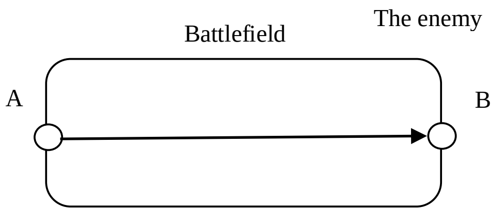

Figure 2. The first strategy

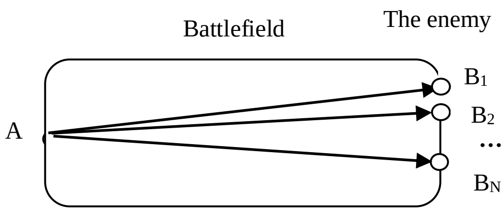

Figure 3. The second strategy

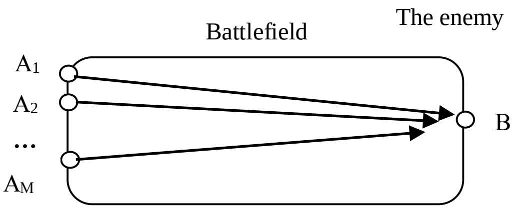

Figure 4. The third strategy

This is a rather simple solution for forming and controlling an attack wave, as the attack drones move independently to the enemy targets (see Figure 4).

4) Strategy for launching a swarm from one location (A). Next, the swarm is divided into groups at the navigation point (C). The number of groups corresponds to the number of targets (B_1, B_2, ..., B_N) (Fig. 5).

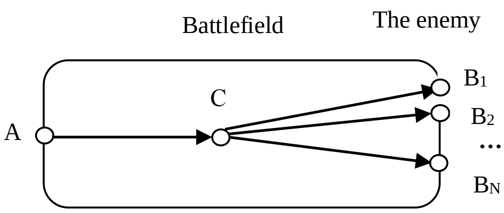

Figure 5. The fourth strategy

The control system provides swarm formation and control of the swarm's flight to point (C), and then the swarm is divided into groups with each group controlling the movement to the enemy targets. This strategy is more complicated than the previous ones.

5) Drones are launched from different locations (A_1, A_2, ..., A_M). Next, the attack drones are combined into a swarm at the navigation point (D). The swarm then flies to point (C), where it is divided into groups

(Fig. 6). Each group attacks its own set of targets at locations (B_1, B_2,..., B_N).

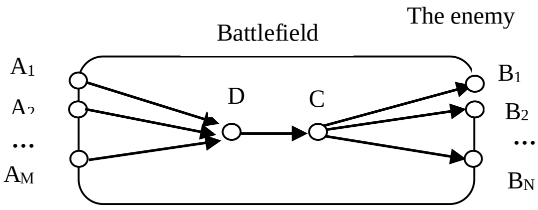

Figure 6. The fifth strategy

The control system is more complex than in the previous strategies.

6) Strategy for launching a swarm of attack drones from a single location (A). Next, the swarm is sequentially divided into groups at several navigation points (C_1, C_2, ..., C_N) (Fig. 7). At each navigation point, one group of attack drones is separated and directed at its target (B_i), $j = \overline{1, N}$.

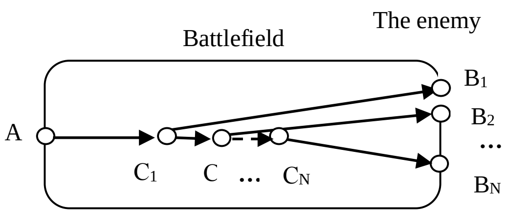

Figure 7. The sixth strategy

The drone swarm control system is even more complex than the previous strategies.

7) Strike drones are launched from different locations (A_1, A_2,..., A_M). Then, the drones are combined into a swarm at the navigation point (D). After that, the swarm moves to the navigation points (C_1, C_2, ..., C_N), where they are divided into groups that move to the targets in places (B_1, B_2, ..., B_N) (Fig. 8).

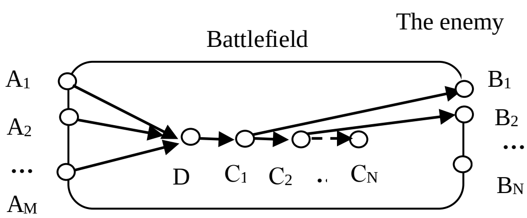

Figure 8. The seventh strategy

The system for managing swarms and groups of drones is more complex than in previous strategies.

8) Strike drones are launched from different locations (A_1, A_2,..., A_M). Then, the drones are combined into a swarm at point (D). The swarm of drones moves through the navigation points (C_1, C_2,..., C_N), each of which is divided into several groups. Then, each group of attack drones moves to its target in a set of locations (B_1, B_2, ..., B_N) (Fig. 9).

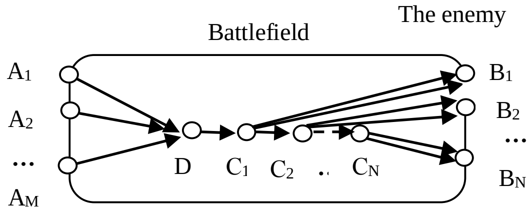

Figure 9. The eighth strategy

This is the most difficult strategy for controlling a swarm and groups of attack drones, as it involves combining drones into a swarm, dividing the swarm into groups, and controlling the flight of the groups to multiple enemy targets.

This list of strategies is not complete and may be complemented by new strategies that arise in the context of modern hybrid warfare.

3. Rational division of a swarm of drones into groups for attacking actions on separate enemy targets

While planning an attack using a swarm of drones, there is an urgent task of dividing the swarm into groups to inflict maximum damage on the enemy. For this purpose, it is necessary to create the necessary combat potential of attack drones to perform attack actions. It is necessary to analyze the military situation on the battlefield and to form a set of actual enemy targets with an assessment of the combat potential required to defeat them. Taking into account the limited capabilities of individual attack drones (flight time, combat load, etc.), the formation of a swarm and its division into groups that will attack enemy targets can be carried out according to different schemes:

1. Complete defeat of a single target or several targets in conditions of limited opportunities to create a swarm of drones. In this case, the combat potential of each group of attack drones (Pj) aimed at the j-th enemy target should ($P_j \geq P_j^*$), where Pj* is the combat potential of the attack drones required to completely defeat the j-th target, $j = \overline{1, N}$; N – the number of actual enemy targets.

2. Not all detected enemy targets can be destroyed. Several targets will be damaged (incomplete defeat). This situation is caused by the limited capabilities of the attack drone swarm to create combat potential. In this case, it is necessary to use the conditions (Pj ≥ Pj'), where Pj' is the combat potential of the j-th group of drones, which makes it possible to create the planned damage to the enemy, which limits its combat actions.

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With limited capabilities to create a swarm of drones with the necessary combat capabilities, it is necessary to rationally divide the swarm into groups, taking into account the priority of the enemy's current targets. Let's prioritize the goals in the form of values α_j ($\alpha_1+\alpha_2+\ldots+\alpha_N=1$). The value of αj depends on the planning of the operational and tactical actions of the military leadership, as well as the current situation on the battlefield (preparation for an offensive, defense, etc.)..

To solve the problem of rationally dividing a swarm of attack drones into groups that will be directed at enemy targets to inflict maximum damage, we will use integer (Boolean) programming. Let's introduce a Boolean variable:

$$x_{ji} = \begin{cases} 1, & \text{if i} - \text{th strike drone is directed} \\ & \text{at the j} - \text{th enemy target;} \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

Then, the combat potential of a group of drones attacking the j-th enemy target is as follows:

$$P_j = \sum_{i=1}^{V_j} p_i x_{ji}, \quad (2)$$

where Vj is the number of drones that will be used for a massive attack on the current j-th enemy target, $V = \sum_{j=1}^{N} V_j, V > N,$

p_i – combat potential of the i-th drone (different attack drones can be used).

Then, the combat potential of a swarm of drones will be:

$$P = \sum_{j=1}^{N}\sum_{i=1}^{V_j} p_i x_{ji}. \quad (3)$$

To consider the priorities of the enemy's current goals, we will normalize the combat of the combat potential of attack drones:

$$P_j = \frac{P_j - P_j'}{P - P_j'}, \quad j = \overline{1, N}, \quad (4)$$

where P is the total combat potential of the drone swarm.

Then, considering the priorities (αj), we form the objective function of optimization in the form of the total (normalized) combat potential of the swarm:

$$P = \alpha_1 \frac{P_1 - P_1'}{P - P_1'} + \alpha_2 \frac{P_2 - P_2'}{P - P_2'} + \ldots$$
$$\ldots + \alpha_N \frac{P_N - P_N'}{P - P_N'} = \frac{\alpha_1 P_1}{P - P_1'} + \frac{\alpha_2 P_2}{P - P_2'} + \ldots$$
$$\ldots + \frac{\alpha_N P_N}{P - P_N'} - \frac{\alpha_1 P_1'}{P - P_1'} - \frac{\alpha_2 P_2'}{P - P_2'} + \ldots$$
$$\ldots + \frac{\alpha_N P_N'}{P - P_N'} =$$
$$= \frac{\alpha_1}{P - P_1'} \sum_{i=1}^{V} p_1 x_{ji} + \frac{\alpha_2}{P - P_2'} \sum_{i=1}^{V} p_2 x_{ji} + \ldots$$
$$\ldots + \frac{\alpha_N}{P - P_N'} \sum_{i=1}^{V} p_N x_{ji} - \frac{\alpha_1 P_1}{P - P_1'} - \frac{\alpha_2 P_2}{P - P_2'} - \ldots \quad (5)$$
$$\ldots - \frac{\alpha_N P_N}{P - P_N'}.,$$

where $\sum_{j=1}^{N} \alpha_j = 1.$

It is necessary to maximize P the maximum damage to the enemy, considering the priorities of the selected current enemy targets:

$$\max P.$$

It is necessary to use the following restrictions:

$$P_1 \geq P_1', P_2 \geq P_2', \ldots, P_N \geq P_N'.$$

To solve the optimization problem, using integer (Boolean) programming, we will use the method of full search (for small dimensions, $n \leq 10$), the method of branches and boundaries (for large dimensions, $10 < n \leq 50$), the method of random search (for very large dimensions, $n > 50$).

Therefore, when dividing a swarm of strike drones into groups, the limited possibilities for forming the combat potential of drones to inflict maximum damage when conducting attack operations against enemy targets are considered.

4. Formation of a set of swarm waves of attack drones depending on the level of damage to enemy targets

Swarm waves of attack drones allow for a massive attack on enemy targets to inflict maximum damage. The number of waves depends on the following possible factors:

- the need for complete defeat of the selected actual enemy targets;

- infliction of such a level of damage that does not allow the enemy to conduct successful combat operations on the battlefield in the future:
- the need to force the enemy to move from active offensive to defense or retreat;
- the goals of a combat operation aimed at seizing the military initiative;
- the need to create, through multiple waves of a swarm of attack drones, asymmetries of military parity of forces, which will allow for successful operational and tactical actions on the battlefield in the future.

To maximize the damage to the enemy (complete defeat, if possible), it is necessary to take into account the combat potential of the swarm of attack drones (P), which is compared with the combat potential of ($\check{P}$), necessary for destruction of selected enemy targets ($P \geq \check{P}$). However, anti-drone and electronic warfare activities used by the enemy when flying to targets lead to the destruction of part of the swarm and therefore ($P' < \check{P}$), where P' – the rest of the swarm's combat potential, which is not enough to completely defeat the targets. Therefore, it becomes necessary to form a new wave of the swarm. Let us represent this wave in the form (e+1). The following requirements must be met ($P_{e+1} \geq \check{P}'_e$), where P_{e+1} – the combat potential of a swarm of drones in the (e+1) wave, which is compared with the potential of $\check{P}'_e$, which is necessary to defeat enemy targets after the e-wave attack of a swarm of attack drones. Assessment of the value $\check{P}'_e$ can be carried out using intelligence data after the e-th attack.

The enemy's anti-drone actions lead to the need to choose a rational strategy, from the set of possible ones, for each e-th wave of a swarm of attack drones to ensure the effectiveness of the attack (see p. 2). Therefore, it is necessary to quickly assess the change in military circumstances on the battlefield and model the effectiveness of using a particular strategy for a new wave of attack drones.

Let's form an optimization model for choosing a rational strategy for conducting a massive attack on enemy targets using a swarm of attack drones. Let us introduce an integer (Boolean) variable:

$$x_{lk} = \begin{cases} 1, \text{ if for the use of the } 1-\text{st strategy} \\ \text{the } k-\text{th composition of logistical military} \\ \text{actions is selected for its implementation;} \\ 0, \text{ otherwise.} \end{cases} \quad (6)$$

Then, the time T_l must conduct logistical military actions to plan the lth strategy:

$$T_l = \sum_{k=1}^{Q_l} t_{lk} x_{lk} , \quad (7)$$

where t_{lk} – is the time required to plan the l-th strategy in the case of using the k-th composition of possible military logistical actions,

Q_l – is the set of possible logistic warfare formations for planning the lth strategy.

The effectiveness of the use of the l-th strategy can be assessed with the help of the military (for example, by using expert scores on the scale 0...10):

$$F_l = \sum_{k=1}^{Q_l} f_{lk} x_{lk} , \quad (8)$$

where f_{lk} – the effectiveness of the l-th strategy, in the case of using the k-th composition of logistics military actions for its implementation.

Risks connected with the implementation of the l-th strategy (depending on possible anti-drone actions of the enemy):

$$R_l = \sum_{k=1}^{Q_l} r_{lk} x_{lk} , \quad (9)$$

where r_{lk} – the risk of using the l-th strategy when choosing
the k-th composition of logistic military actions for its realization.

To perform effective combat operations with a swarm of attack drones, it is necessary to:

$$\max F_l, \; F_l = \sum_{k=1}^{Q_l} f_{lk} x_{lk} , \quad (10)$$

considering the restrictions on the permissible time for planning a massive attack with strike drones in the eighth wave of the swarm:

$$T_l \leq T^*, \; T_l = \sum_{k=1}^{Q_l} t_{lk} x_{lk} , \quad (11)$$

as well as limiting the risk of a successful attack by a swarm of attack drones:

$$R_l \leq R^*, \; R_l = \sum_{k=1}^{Q_l} r_{lk} x_{lk} , \quad (12)$$

where $l = \overline{1,s}$, s – is the number of strategies that can be chosen to conduct an attack in the e-th wave, T*, R* is the allowable time and risks of planning attack actions.

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The T*, R* rating is set by the military, considering the situation on the battlefield, as well as the operational-tactical tasks of the military leadership.

If one wave is not enough to completely defeat enemy targets, then it is necessary to use multiple waves of strike drones with different strategies to ensure stealth and the suddenness of the attacking actions.

5. Formation of a swarm flight mission of attack drones

When developing a swarm flight mission, it is necessary to assess the military situations on the battlefield. Therefore, it is necessary to conduct a preliminary analysis of the air situation on the battlefield by conducting reconnaissance activities. It is advisable to divide the airspace in the conflict zone into local zones (LZs) that have different levels of enemy threats (use of anti-drone weapons, interceptor drones, electronic warfare, etc.). Next, it is necessary to create a map for planning the flight routes of attack drones. The map will show a set of LZ ($E_1, E_2, \ldots, E_w$) with the value of the threat risks R_z, $z = \overline{1, w}$. To form relatively safe flight paths, it is necessary to form a trajectory with the Rz values of each LZ in the flight map. Next, we take into account the choice of the right strategy for flight planning, and mark on the flight map the set of navigation points (A, B, C, D) where the swarm will be formed, divided into groups, and fly to enemy targets. In this way, a labeled map will be created to plan the flight missions of a swarm of attack drones.

When forming flight routes for a swarm of drones (groups, individual attack drones), it is necessary to provide minimal travel time to targets for a sudden massive strike in the face of enemy anti-drone operations.

We propose an original algorithm for finding routes for attack drones that ensures the minimum flight time to targets, taking into account the actions of possible enemy threats. The algorithm is based on the simulation modeling of the main events in the mission of attack drones.

Step 1. Let's form a map of the air situation on the battlefield in the form of a set of aircraft ($E_1, E_2, \ldots, E_w$), which are labeled with the values of military threat risks ($R_1, R_2, \ldots, R_w$).

Step 2. After analyzing the level of possible enemy threats, we will enter the permissible risk R* of passing the line of defense by a swarm of drones. On the drone flight map, zones will be formed that are not recommended for drone movement. If most of the LZs have a risk of $R_z \geq R^*$, then the value of R* must be changed, otherwise it will be impossible to move the drones for combat operations.

Step 3. From the starting point of flight (A) (and then from the z-th point), a request is formed (this is how we will represent a swarm, group, or individual drone in the future, using the terminology of simulation modeling), which is divided into copies (clones). They move in parallel, in time, to all neighboring LZs (hereinafter, in (z+1) LZs).

Step 4. The limits on the permissible risk of the order (clone) entering the neighboring (z+1) LZ ($R_{z+1} \leq R_{z+1}^*$) are checked. If this restriction is not complied with, then the application (clone) does not get to the neighboring (z+1) LZ, in which ($R_{z+1} > R_{z+1}^*$) and its movement is stopped.

Step 5. If an application (clone) is placed in the next (z+1) LZ, with the condition ($R_{z+1} \leq R_{z+1}^*$), then this LZ is marked, if it was not taken by an application (clone) that was received earlier.

Step 6. If an application (clone) has entered the adjacent LZ using the condition ($R_{z+1} \leq R_{z+1}^*$), and it has already been marked by another application (clone), its movement is stopped because it has a longer movement time than the previous application that previously entered the (z+1) LZ.

Step 7. If the application (clone) successfully enters the (z+1) LZ, the application (clone) is divided into copies, which then move to the neighboring LZs.

In this way, the neighboring (z+1) LZs deal with applications (clones) that are most competitive in terms of travel time.

Next, steps 5, 6, 7 are repeated. A set of applications (clones) emerges that compete with each other and move in parallel in time to the goals at the point (B).

The steps are repeated.

(n-1) step. The most competitive application (clone) in terms of movement time gets to the target (B), after which the movement of other applications (clones) stops.

n-th step. The shortest in time and relatively safe flight route of the swarm (group, individual drones) is formed on the flight map, in the form of a sequence of marked LZs, starting from point (A) and ending with the finish point (B) (enemy target).

6. A multi-agent model for planning the flight paths of a swarm of strike drones

A software model of the movement of a swarm of attack drones to enemy targets using discrete-event simulation modeling has been developed. The simulation time scale depends on the following factors:

- the size of the airspace used for the flight of attack drones;
- time-sensitive tasks of the military leadership;

- requirements for the real-time control of a swarm of attack drones;

- modeling accuracy.

The simulation model was created in the Any Logic agent-based modeling environment and consists of a set of developed agents. Each agent displays the dynamics of swarm behavior, considering the chosen strategy (see Section 2). The modeling was carried out on a map with a set of local zones of the airspace of the battlefield. Each agent has its own variables and an internal model that describes the logic of its behavior over time. The developed multi-agent model is open for replenishment with new agents, which will allow, for example, a more detailed analysis of combat operations with the help of attack drones.

The set of agents used in modeling:

1. The "flight map" agent. A set of LZs of the air area of the battlefield is formed. Each aircraft has a risk assessment, which is assigned depending on the enemy's anti-drone threats.

2. The "starting point of flight" agent. One (A) or a set (A_1, A_2,...,A_M) of navigation points from which the attack drones will be launched are specified on the flight map.

3. Agent "enemy target". A navigation point (B) or a set (B_1, B_2, ..., B_N) is specified, which are used as the finish points of the flight of a swarm of drone strikes (enemy targets).

4. Agent "intermediate flight point". A navigation point (C) or a set of navigation points (C_1, C_2, ..., C_N) is set, which are used to divide the swarm of drones into groups. In addition, a point (D) is set to form a swarm of drones in flight.

5. Agent "wave attack strategy". It is used to select the strategy of attacking with a swarm of attack drones (see section 2).

6. Agent "movement modeling". It is used to simulate the movement of drones in time when moving from one navigation point to another.

7. Agent "threat creation". This agent simulates the occurrence of a threat and forms a ban on the drone's passage through the z-th LZ where the threat arose.

8. Agent "drone destroyer". Simulates the loss of a share of the drone swarm due to enemy actions.

9. The "route change" agent. The drone flight route is changed due to changes in the circumstances on the battlefield. This can be done manually or in the automatic mode. In the automatic mode, the neighboring (z+1) LZ is used as the next (z+1) LZ to continue the flight, and the LZ with the lowest threat risk value is used.

10. The "optimal route" agent. It is used to search for the minimum time route according to the developed algorithm for finding the optimal route (see section 5).

11. The "navigation calculations" agent. It is used to create a flight map and calculate the time of movement of the drones in the local flight zones.

12. The "modeling results" agent. It is used to generate the results of modeling the flight of attack drones to enemy targets. The modeling results include:

- swarm flight routes (groups, individual drones);

- change of flight routes of attack drones (new flight routes due to enemy threats);

-the flight time of a swarm of attack drones to enemy targets;

- the overall risk of a drone swarm flight, which is formed by summing up the individual risks during the passage of the line of sight that arise along the drone flight route;

- the flight time of the drone swarm, considering the actions of military threats;

- the number of drones in the swarm that successfully reached enemy targets;

- level of damage to enemy targets.

13. The "modeling interface" agent. This agent is used to interactively simulate the movement of a swarm of attack drones using the selected strategy.

Fig. 10 shows a block diagram of the multiagent model.

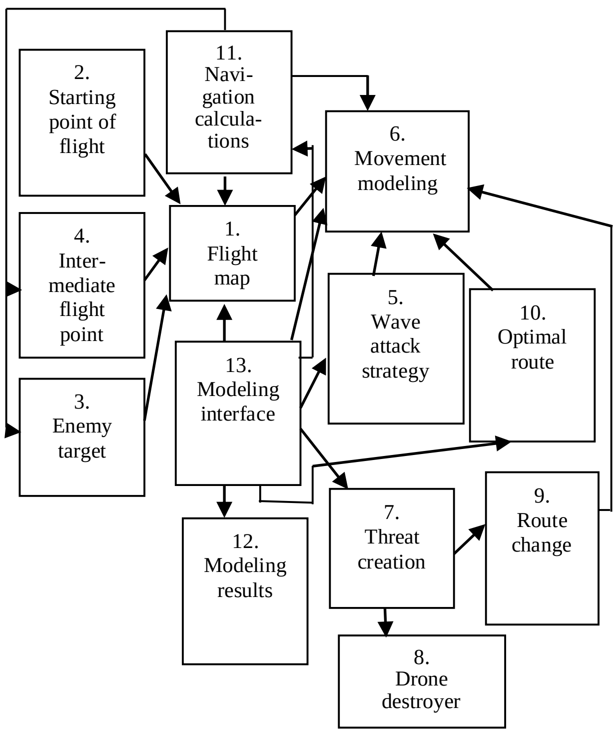

Figure 10. Block diagram of the multi-agent model

Let us briefly present the sequence of actions of the researcher when using a multi-agent model to plan the flight routes of a swarm of strike drones.

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With the help of agent 13 "modeling interface", agent 1 "flight map" is initiated, which allows the formation of a map with a set of local zones, taking into account the air situation on the battlefield and navigation points of flight. Navigation points are set with the help of agents: 11 "navigation calculations", 2 " starting point of flight", 4 "intermediate flight point", 3 "enemy target". Next, a wave attack strategy is selected using agent 5 "wave attack strategy". The route of the swarm of strike drones was set and simulated in time using agent 6 "movement modeling". If route optimization is used, agent 10 "optimal route" is used. To study the effect of enemy threats on the flight of a swarm of drones, it is necessary to use agent 7 "threat creation" and agent 9 "route change", as well as to model the loss of attack drones using agent 8 "drone destroyer". At the end of the simulation of the flight of the swarm of attack drones, agent 12 "modeling results" is initiated.

Modeling is performed multiple times, corresponding to the number of waves of the swarm of strike drones. The simulation results can be statistically averaged.

7. An illustrated example of modeling attack actions using a swarm of the attack drones

Let's look at an example of modeling attack actions by a swarm of attack drones using the fourth attack planning strategy (see Section 2). For the fourth strategy, the formed swarm of attack drones takes off from the launch point (navigation point (A)) and moves to the navigation point (C). At point (C), the swarm is divided into two groups. The first group moves to the first target (navigation point (B_1)), and the second group moves to the second target (navigation point (B_2)).

Fig. 11 schematically shows a map of the wind conditions on the battlefield in the form of a set of LZs with navigation points. Local zones have different risks from possible military threats (enemy anti-aircraft operations, use of electronic warfare, etc.):

R_1=28% R_9=55% R_{17}=62% R_{25}=60%
R_2=29% R_{10}=48% R_{18}=63% R_{26}=76%
R_3=38% R_{11}=52% R_{19}=64% R_{27}=81%
R_4=35% R_{12}=51% R_{20}=58% R_{28}=82%
R_5=33% R_{13}=38% R_{21}=55% R_{29}=83%.
R_6=32% R_{14}=55% R_{22}=58%
R_7=29% R_{15}=51% R_{23}=31%
R_8=48% R_{16}=51% R_{24}=32%

Let's set the allowable values of the risk of movement of a swarm (group) of attack drones when passing the line of defense R^*=65%. Such a rather large risk value is associated with the need to overcome those lines of defense that are located near the targets (navigation points (B_1) and (B_2)) with a high risk value due to enemy actions. Next, let's define LZs with very high risk values ($Rz>R^*$). These include: R_{26}, R_{27}, R_{28}, R_{29}, which will not be used because they will be prohibited for the movement of a swarm (group) of attack drones (shaded on the map) (see Fig. 11).

Next, a matrix was created (Table 1), which shows the distances in time (minutes) the drones moved through the LZ. On the flight map (Fig. 11), we designate LZ 1, where the navigation point (A) is located (launch of the drone swarm), LZ 6, where the navigation point (C) is located and the swarm is divided into two groups, LZ 17, where the navigation point (B_1) is located (the first target), LZ 19, where the navigation point (B_2) is located (the second target), and LZ 19, where the).

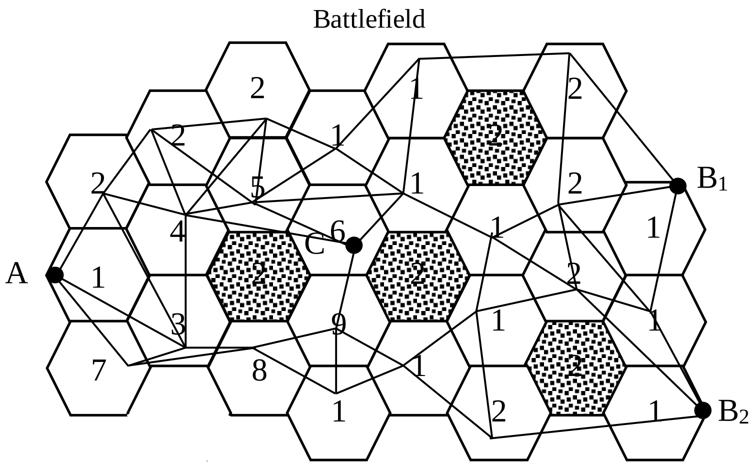

Figure 11. Schematic representation of the air situation map on the battlefield

Table 1

Distances in time (minutes) during the movement of drones through the LZ

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		3	6				5																		
2			3	3																			5		
3				3				5																	
4					6	4																	3	6	
5						6						5	4											3	
6									4			6													
7								3																	
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19																									
20																		3	8						3
21																			4						
22																	3								8
23					5																			5	
24													8												
25																	5	3							

To form the routes of movement of a swarm (group) of attack drones to enemy targets, the developed algorithm for finding the shortest flight route in time, under the given constraints on the risk values, was used. The minimum time movement of the drones to the navigation point (C), where the swarm will be divided into groups, has the form of the sequence of LZ: 1-2-4-6, with the time value T_S = 10 min.

After dividing the swarm of drones into groups, at the navigation point (C), the first group moves to the first target (navigation point (B_1)). The route with the minimum time of movement of the drones was found using the developed optimization algorithm for finding routes (see section 5) and has the form: 6-12-14-22-17, with the time value T_{V1}=17 minutes. The second group moves from the navigation point (C) to the second target (navigation point (B_2)). The flight path of the drones with the minimum time value is found, which has the form: 6-12-15-20-18-19, with the time value T_{V2}=22 minutes.

Therefore, the flight time of the attack drones to the target (B_1) matters: T_S+T_{V1}=10+17=27 minutes. The flight time of the attack drones to the target (B_2): T_S+T_{V2}=10+22=32 minutes.

For the planned flight time that was calculated, it is advisable to use drones of class 1 or 2 (military gradation, in which class 1 – multicopters, class 2 – aircraft-type drones with a duration of use of up to 3 hours).

To use multiple waves of attack drones, it is necessary to model the possible damage to drones when they approach enemy targets (see section 4). The number of swarm waves depends on the necessary level of target damage (up to complete defeat), as well as on the limitations on the allocation of attack drones to the military for combat operations on the battlefield.

8. Discussion

A systematic representation of logistical military operations for planning massive wave attacks using a swarm of attack drones is created.

A set of scenarios for conducting attacks by attack drones against enemy targets is analyzed.

A rational division of a swarm of drones into groups aimed at locally concentrated actual enemy targets is carried out.

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It considers the combat capability of individual drones to form a swarm combat potential capable of inflicting damage to the enemy, up to complete destruction, using waves of attack drones. The number of waves depends on the combat potential of the swarm, which may decrease when approaching enemy targets due to anti-drone actions.

A map of drone flights on the battlefield is generated, indicating the navigation points where a swarm of drones is formed, and its division into groups is carried out.

The flight map is divided into local zones depending on the risk of military threats from the enemy.

Much attention in the study is paid to planning the flight routes of a swarm (group) of attack drones in the conditions of enemy anti-drone actions. Therefore, an original routing algorithm has been developed that considers the existing restrictions on the movement of drones in the form of the risk of flying through certain local zones. The algorithm allows the formation of a trajectory of drone movement to targets in the shortest possible time, which ensures the suddenness of a massive attack by a swarm of drones on the battlefield.

The created model allows us to study the attack missions of the attack drones. Using the created interactive interface, drone flights are modeled on a map with a given value of the time scale.

An agent-based model was developed to study the sequence of logistical actions during wave attacks by a swarm of successful drones. The structure and composition of the agent model are presented.

An illustrated example of using the proposed approach to plan a massive attack by strike drones against enemy targets is given.

The research methodology consists of the following stages:

1. Systematic analysis of planning strategies for massed attacks using swarm waves of attack drones.
2. Formation of a swarm of attack drones to inflict planned damage on the enemy.
3. Dividing a swarm of attack drones into groups, depending on the choice of a set of actual enemy targets.
4. Planning the flight of attack drones despite enemy anti-drone actions.
5. Creation of an algorithm for finding relatively safe flight paths for drones to enemy targets.
6. Agent-based modeling of the attack missions of a swarm of attack drones.

The actuality of the proposed approach is related to the need to use waves of swarms of attack drones to conduct attack actions against enemy targets, in conditions of limited capabilities, to establish military force equality.

The developed set of models is aimed at planning rational logistical military actions for the use of combat drones in the form of a swarm to inflict maximum damage on the enemy. This allows us to conclude that the proposed approach is timely and effective in planning operational and tactical actions on the battlefield, using an innovative technological tool of war in the form of waves of swarms of attack drones.

Future research will focus on improving the applied information technology for planning combat operations using swarm waves of strike drones for use by the military.

9. Conclusions

The conducted research allows, after analyzing the circumstances on the battlefield, as well as the military mission during combat operations, using strike drones:

- choose the necessary strategy for performing an attack with strike drones;
- to form a drone swarm with the necessary combat potential, considering the limited capabilities of drones;
- justify the set of actual enemy targets, taking into account the capabilities of the drones (flight time, combat load, etc.);
- set the necessary navigation flight points to divide the swarm into groups;
- form flight routes considering the enemy's anti-drone actions;
- justify the number of attack waves to inflict maximum damage on the enemy.

Therefore, we can draw the main contribution from the research conducted:

The proposed complex of models allows, when planning operational-tactical military actions, the use of an innovative element of modern warfare, in the form of a swarm of attack drones, to carry out attacks on enemy targets, which will ensure the success of offensive operations on the battlefield.

The scientific novelty of the study is associated with the creation of a set of models that allow planning logistical military actions to conduct massive attacks with waves of strike drones.

Contribution of authors: systematic representation of strategies of combat operations with strike drones – **Oleg Fedorovych**; flight control, swarm formation, division into groups of strike drones – **Dmytro Krytskyi**; optimization of the division of a swarm of drones into groups – **Mikhail Lukhanin**; simulation and agent modeling, logistics military operations with the help of strike drones – **Oleksandr Prokhorov**; an example of modeling combat operations with strike drones – **Yuliia Leshchenko**.

Conflict of Interest

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

Financing

This study was conducted without financial support.

Use of Artificial Intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, as described in the research methodology section.

Data Availability

The work has associated data in the data repository.

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

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МОДЕЛЮВАННЯ МІСІЙ УДАРНИХ ДРОНІВ ДЛЯ ПРОВЕДЕННЯ ХВИЛЬОВИХ АТАК, В УМОВАХ ПРОТИДРОНОВИХ ДІЙ ПРОТИВНИКА

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Формується та вирішується актуальна задача дослідження військових логістичних дій щодо формування місій рою ударних дронів для проведення масованих атак по цілях противника. Дослідження, яке проводиться спрямоване на планування бойових атак дронами для забезпечення становлення військового паритету сил у зоні воєнного конфлікту. Тому, актуальна тема запропонованої публікації, в якій досліджується послідовність військових логістичних дій для планування та здійснення хвильових атак для нанесення максимальних збитків противнику. Метою публікації є створення комплексу математичних, імітаційної та агентної моделей, за допомогою яких досліджуються та плануються місії атак хвилями рою ударних дронів. Проаналізовані існуючі проблеми використання нового інноваційного технологічного інструменту війни у вигляді рою ударних дронів. Проводиться системний аналіз військових логістичних дій щодо проведення масованих атак ударними дронами. Формується множина стратегій використання рою дронів на полі бою. Розглянуті можливі дії, які пов'язані з запуском дронів, формуванням рою у польоті, розподілом рою на групи з їх рухом до відокремлених цілей противника. Враховуються ризики військових загроз противника (використання засобів РЕБ, протидронова боротьба, тощо), які впливають на формування маршрутів та можливе знищення частки ударних дронів при підльоті до цілей. Проводиться раціональний розподіл рою на групи в польоті, з урахування бойового потенціалу необхідного для ураження актуальних цілей противника. Формується послідовність хвиль рою дронів в залежності від рівня ураженості цілей (часткове ураження, повне ураження). При плануванні кожної хвилі польоту дронів застосовується одна із запропонованих стратегій. Велика увага приділяється формуванню маршрутів польоту ударних дронів для забезпечення раптовості масованої атаки в умовах військових загроз противника. Розроблено алгоритм формування найкоротшого у часі маршруту польоту в умовах протидронових дій противника. Формується мапа повітряних обставин на полі бою з множиною відокремлених локальних зон, які мають різні значення ризиків загроз. Проведення маршруту здійснюється з урахуванням військових ризиків кожної локальної зони. Створена імітаційна модель для дослідження, у часі, руху ударних дронів до цілей противника. Розроблюється агентна модель для планування військових логістичних дій щодо проведення хвильових атак по цілям противника за допомогою рою та груп ударних дронів. Наведено ілюстрований приклад планування маршрутів польоту рою ударних дронів з урахуванням ризиків військових загроз. Наукова новизна дослідження пов'язана з вирішенням актуальної науково-прикладної задачі планування місій рою ударних дронів для забезпечення успішних оперативно-тактичних дій на полі бою. Результати дослідження доцільно використовувати військовими для планування та проведення атакуючих дій по цілям противника у вигляді хвиль рою ударних дронів.

Ключові слова: рій ударних дронів; планування місій хвильових атак; бойовий потенціал дронів; оптимальний маршрут польоту; імітаційна модель; агентна модель.

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