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MODELING THE SERIES OF MILITARY ACTIONS TO PLAN AN ATTACK MISSION OF A SWARM DRONES

*The use of unmanned aerial vehicles (UAVs) has become an innovative technological tool in modern hybrid warfare. The effectiveness of UAVs has increased dramatically when combat drones are deployed in swarms to attack enemy targets. The creation of an active shield in the air to help the military on the ground allows for the integration of air and ground combat operations, which gives a new synergistic effect to the use of attack drones. Therefore**, it is relevant** to conduct a study on the planning of attack missions using attack UAVs. **The subjects of this research are** models used to plan attacking military operations using attack drones. **The purpose** of this study is to create a set of models that enable planning massive attacks by attack drones**. Tasks** to be solved: to form a sequence of military actions for an attack mission; to justify the choice of local military zones for an attack; to form the combat potential of a swarm of drones; to justify the use of simulator drones to deplete enemy resources; to form waves of a swarm of attack drones; to model the movement of the swarm to the targets. The mathematical **methods and models** used are: system analysis to form an attack mission of attack drones; method of virtual experiment to select important indicators of enemy activity; method of qualitative assessment of enemy actions; method of lexicographic ordering of options to select relevant military local zones for attack; integer (Boolean) optimization to create the necessary combat potential to defeat enemy targets; simulation multi-agent modeling of the flight of a swarm of attack drones. The following **results** were obtained: a systematic representation of the sequence of military actions for conducting an attack by attack drones was obtained; indicators of enemy activity were substantiated; a set of actual military local zones with enemy targets was formed; a swarm of simulator drones was created to distract the enemy; the necessary combat potential of the attack drone swarm was formed; waves of attack drones were substantiated to defeat enemy targets; and a simulation, multi-agent model of swarm movement was created. **Conclusions**. The results of the study make it possible to substantiate a plan of combat operations using a swarm of attack drones, which contributes to the effectiveness of operational and tactical actions on battlefields. The novelty of the proposed approach lies in the scientific substantiation of the sequence of military actions for planning the attack mission of attack drones, using the developed set of original and new mathematical and simulation models.*

Keywords: *swarm of strike drones; wave attack by drones; multiple local military zones with actual targets; indicators of enemy activity assessment; optimization of the combat potential of a swarm of strike drones; simulation and agent-based modeling of military operations; wave attack by strike drones.*

1. Introduction

The emergence of a new technological tool for war, in the form of UAVs, changed the tactics of warfare on the battlefield [1, 2]. The integration of military operations, both in the air and on the ground, has increased defense capabilities by creating an active air shield that forms a Kill Zone on the ground to resist enemy attacks [3, 4]. However, the enemy's availability of anti-drone capabilities complicates the use of combat UAVs [5, 6]. Therefore, the deployment of UAVs in a swarm provides a new synergistic effect that affects the effectiveness of combat operations and the conduct of a massive attack on enemy targets. The realization of enemy military threats may lead to a partial loss of drones in the swarm, but still, most drones reach their targets [7, 8].The realization of enemy anti-drone actions leads to the need to form waves of attack drones that can be launched in the amount necessary to completely defeat enemy targets [9, 10]. Therefore, there is a difficult task of planning UAV military missions using waves of swarms of attack drones. It is necessary to form a systematic sequence of military actions to conduct an attack mission using a swarm of attack drones [11, 12].While planning an attack, it is necessary to analyze the results of monitoring the military situation on the battlefield using reconnaissance drones; launch imitator drones to distract the enemy and deplete its military resources; analyze the results of the attack, assessing the level of damage to targets, which allows to calculate the number of wave attacks and plan their sequence. All these activities are necessary in the face of active enemy anti-drone operations, which complicates the planning and conduct of an attack mission using a swarm of attack drones. Taking into account the above, we conclude that it is relevant to conduct a study on the planning of wave air attacks using a swarm of attack drones.

1.1. Motivation

Planning an attack mission using a swarm of attack drones is a complex task, as it is necessary to take into account the dynamic changes in military circumstances on the battlefield, the availability of enemy anti-drone capabilities, the creation of the necessary combat capability of the drone swarm to defeat enemy targets, etc. While planning an attack mission using attack drones, it is necessary to form a set of enemy targets and select the actual targets to be attacked, taking into account the limited capabilities of UAVs (flight time, flight range, flight altitude, payload, etc.).For the effective use of combat drones, it is necessary to launch imitator drones before the attack to distract the enemy and deplete its military resources. Next, it is necessary to organize the movement of drones to enemy targets. After defeating the enemy's targets, it is necessary to analyze the results of the attack and, if necessary, form a new wave of attack drone swarms.

Therefore, the task of planning wave attacks by a swarm of attack drones to support military operations on the battlefield is urgently needed.

1.2. State of the art and problem statement

There are several problems connected with the use of UAVs for attack missions. Some problems are being solved, but there are also new problems that require research:

1. Formation of a strategy for planning a multi-stage sequence of military operations to conduct an attack mission using a swarm of attack drones. For example, study [13] mathematically describes interaction options, but does not provide for multi-stage use to achieve the goal, and study [14] proposes the idea of using a swarm of drones to create artificial precipitation, taking into account repeated and multi-stage use, but does not provide for interaction between them and the direction of each to obtain one specific result by performing various tasks.

2. Monitoring of changes in military circumstances on the battlefield using reconnaissance drones to make decisions about conducting a massive attack with strike drones. Such an issue is, on the one hand, being studied, namely the use of drones for monitoring and reconnaissance activities [15, 16], but only as a separate task, i.e., other studies only show the ability to perform such a task without specific algorithms for interaction between reconnaissance drones and all other agents in order to decide on further actions.

3. The use of imitator drones to distract the enemy and deplete its combat resources. This means that it is necessary to create intelligent drones that are capable of performing such a mission, as described in [17, 18], but simply using smart drones that can work in a swarm is not enough, since these agents need to work on solving the task of distracting and exhausting the enemy, and this requires special algorithms for interaction between drones in a swarm and the behavior of the mission in general.

4. Formation of a swarm of drones, considering the limited capabilities of individual UAVs, to develop the necessary combat capability to defeat enemy targets. Today, this is best described in works on drone interaction during shows or interaction in an urban city [19, 20], but the problem is that the limitations in such works do not coincide with the limitations of interaction between drones during military missions.

5. Planning flight routes for a swarm of attack drones despite enemy anti-drone actions. To perform this task, it is possible to use modern approaches based on neural networks; for example, deep neural networks can be used to obtain more effective solutions. For example, in [21], the authors used a neural network to compare leaves, with the main idea being to use the leaf skeleton; thus, leaf skeletons can be interpreted into a set of possible trajectories, which will add unpredictability to the swarm. Some publications already describe the experience gained during combat operations [22]; however, they do not provide algorithms for swarm actions under such conditions.

6. Real-time analysis of the results of attack operations by attack drones, changes in military circumstances. The works [23, 24] described the possibilities of using a swarm of drones in combat conditions to obtain visual information and how it is possible to plan movement routes in such conditions, but did not take into account that this information is relevant in real time and not after a long period of time.

7. Creation of a new UAV control functionality that allows drones to be collapsed into a swarm and to distribute combat drones into groups aimed at enemy targets. In modern works [25, 26], attention is paid to the formation of a formation and further movement in this formation without considering the possibility of constant change of formations to increase the efficiency of the task.

This is not a complete list of the problems that keep growing in the context of modern hybrid warfare, which indicates the relevance of conducting research on planning an attack mission using waves of swarms of attack drones. The analysis of publications on the above problems showed the complexity of the task of using a

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swarm of drones to support the military on the battlefield [27, 28]. The large number of sensors required on board complicates the drone's design, and processing large amounts of data places additional demands on hardware and software. This paper presents solutions to some of these urgent problems.

1.3. Objectives and methodology

There is a contradiction between the need to use a new innovative tool of war, in the form of a swarm of drones, to further integrate combat operations in the air and on the ground, and the imperfection of existing methods, models and information technologies that will allow for a full systematic analysis of UAV attack missions, and the formation of a sequence of military actions to be taken to effectively use attack drones on the battlefield [29].

The research methodology is based on a systematic representation of military actions to prepare an attack mission using a swarm of attack drones. The methodology includes the following steps:

- analysis of the combat situation on the battlefield, which allows the military leadership to form a set of military local zones (MLZs) in which enemy targets are located or active military operations are conducted;
- assessment of enemy activity using indicators that reflect combat operations, the movement of military equipment and preparation for combat;
- formation of a set of relevant VLZs for a massive attack, in conditions of limited opportunities for the formation of a swarm of attack drones;
- analysis of possible actions of imitator drones to distract the enemy. Formation of the required number of simulator drones to simulate an attack at the locations of anti-drone assets;
- justification of the combat potential of the drone swarm and its rational distribution by direction of movement to enemy targets;
- forming the required number of waves of a swarm of attack drones to maximize the damage to enemy targets;
- modeling the movement of attack drones to enemy targets with an assessment of their possible defeat.

The purpose of this study was to create a set of mathematical and simulation models that can be used to plan the sequence of military actions to conduct wave attacks with strike drones. Following the research objective, the following tasks must be solved:

1. Propose a strategy for planning military operations to conduct an attack mission with strike drones.
2. Form indicators of enemy activity.
3. Select the current enemy targets.
4. Form a swarm of imitator drones.
5. Create an attack drone combat capability.
6. Form waves of swarms of attack drones.
7. Develop a multi-agent simulation model of the movement of an attack drone swarm.
8. An example of modeling an attack by attack drones is provided.

The article is structured as follows:

Section 2 is devoted to the formation of a multi-stage military action plan for conducting an attack mission with strike drones.

Section 3 describes the formation of indicators for assessing the military situation on the battlefield, the values of which affect decision-making regarding a massive attack by attack drones.

Section 4 discusses the assessment and selection of local military zones to defeat actual enemy targets using attack drones.

Section 5 discusses the use of a swarm of simulator drones to deplete enemy resources before conducting a massive attack with attack drones.

Section 6 discusses the formation of the combat potential of strike drones in conditions of limited capabilities.

Section 7 is devoted to the justification of the number of waves of an attack drone swarm that inflicts tangible losses on the enemy.

Section 8 discusses the creation of a simulation model in a multi-agent representation for planning the routes of attack drones to enemy targets.

Section 9 illustrates, by way of example, the effectiveness of the proposed approach for planning an air attack using a swarm of attack drones.

Section 10 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.

Section 11 concludes the article by summarizing the conclusions and providing prospects for further research and development of applied information technology for planning wave air attacks using a swarm of attack drones.

2. A strategy for planning military operations during an attack mission with strike drones

The analysis of combat operations using attack drones has revealed the need to improve air operations to help the military on the ground by creating an active air shield for infantry on battlefields. However, this requires the formation of a strategy to create a sequence of military actions that must be planned for effective use by attack drones. We present the strategy of these planned activities in the form of stages necessary for the use of attack drones for the successful implementation of operational and tactical actions on the battlefield:

1. Monitoring the military situation on battlefields with the help of reconnaissance drones. This makes it possible to form a set of military local zones (MLZs) where enemy activity can be observed.

2. Formation of a set of actual enemy targets to be destroyed in the first place. This task can be accomplished given the limited capabilities of UAVs and the risks associated with enemy anti-drone operations.

3. Simulate an attack with the help of simulator drones. This helps distract the enemy and deplete its resources, as well as helps to clarify the location of anti-drone assets.

4. Formation of the combat potential of attack drones during an attack mission. To achieve this, it is necessary to analyze the enemy's current targets to assess the combat potential required to defeat the enemy.

5. An attack can be conducted using a swarm of attack drones. After a massive attack, assess the level of damage to enemy targets using reconnaissance drones. In conclusion, we consider the use of a new wave of attack drone swarms.

6. A wave attack is conducted with attack drones. Decision-making regarding a new wave attack and the required number of swarm waves for attack drones, considering the level of damage to enemy targets and limited capabilities to create swarm waves.

This list of stages is not final. It can be extended to consider new air innovations that arise in the context of modern hybrid warfare.

The complexity of planning and implementing these stages led to the use of a set of different mathematical models in the study, which are necessary for modeling possible scenarios of combat operations in the air using a swarm of attack drones. Therefore, for the analysis of each stage of the formed strategy, the study used the following:

- systematic analysis of the sequence of military operations using an attack drone swarm;
- method of virtual experiment using the opinions of military experts to identify the priority of indicators of enemy activity in the area of military conflict;
- method of analyzing a set of local military zones to select the most relevant ones for conducting attacks on enemy targets, using lexicographic ordering of options and qualitative assessments of experts;
- method of forming the combat potential of a swarm of attack drones necessary to defeat actual enemy targets, considering the limited capabilities of UAVs, using integer (Boolean) programming;
- method of simulation, agent-based modeling of the flight movement of a swarm of drones in the conditions of enemy anti-drone operations. Simulation modeling was used to simulate the flights of reconnaissance drones, simulator drones and attack drones.

Therefore, in this section, a systematic analysis of the sequence of military actions was carried out to plan an attack mission using attack drones; the main stages of planning a massive wave attack by a swarm of attack drones were presented; a set of methods and models used in the study was formed. This allows us to scientifically substantiate the research methodology for planning an attack mission of combat drones in the context of modern hybrid warfare.

3. Indicators of enemy activity

In order to make decisions about conducting a massive attack on enemy targets using a swarm of attack drones, it is necessary to present, based on the results of intelligence, a set of military local zones (MLZs) in which active enemy actions are observed. Fig. 1 shows a graphic diagram of combat operations on the battlefield using a swarm of attack drones.

After the drones are launched, a swarm is formed, which moves to a set of enemy targets. Next, the swarm is divided into groups, each of which moves to the selected AOE to conduct an attack on enemy targets. The enemy, with the help of anti-drone means (ASW, EW, air defense), forms a defense that affects the possibility of a successful attack.

Constant monitoring of airspace with the help of reconnaissance drones allows assessment of changes in military circumstances and identification of airspace where the enemy is active. To assess changes in the military situation in a particular air defense area, it is necessary to form indicators whose value affects decision-making regarding the conduct of an attack mission using a swarm of attack drones. An analysis of modern military operations on battlefields has shown that enemy activity can be assessed using the following indicators:

1. Accumulation of military equipment (F).
2. Formation of military groups (P).
3. Active actions to move military equipment and other equipment (Q).
4. Engineering works to create military facilities (V).

This is not a complete list of indicators that can be supplemented with new ones in the context of modern hybrid warfare. The use and evaluation of the indicators (F, P, Q, V) to analyze the military situation on the battlefield will help make the final decision on conducting an attack mission with the help of attack drones. We will evaluate the impact of the indicators on decision-making regarding attacks with the help of military experts.

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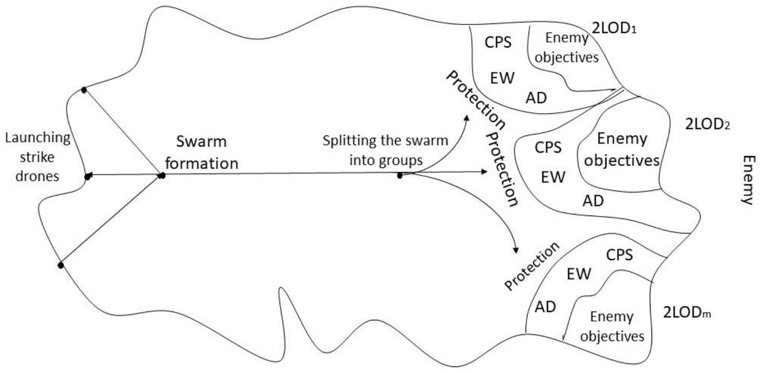

Fig. 1. Graphic diagram of the battlefield

For example, on a point scale (0÷10). We will conduct a virtual experiment with military expert assessments based on the full factorial experiment (FFE) method. The FFE method allows the assessment of the importance (influence) of indicators (F, P, Q, V) for assessing the situation in a particular air defense area and for making decisions on conducting a massive attack with strike drones. Here is an illustrated example of the use of FFE by military experts to assess the importance (influence) of indicators (F, P, Q, V). Table 1 presents the FFE plan with four factors, each of which corresponds to a separate indicator (F, P, Q, V).

Table 1

Plan for a virtual experiment, using expert opinions

№	X_1 (F)	X_2 (P)	X_3 (Q)	X_4 (V)	Y response (expert assessment) of experts)
1	-1	-1	-1	-1	0
2	-1	-1	-1	+1	1
3	-1	-1	+1	-1	3
4	-1	-1	+1	+1	4
5	-1	+1	-1	-1	2
6	-1	+1	-1	+1	3
7	-1	+1	+1	-1	5
8	-1	+1	+1	+1	6
9	+1	-1	-1	-1	4
10	+1	-1	-1	+1	5
11	+1	-1	+1	-1	7
12	+1	-1	+1	+1	8
13	+1	+1	-1	-1	6
14	+1	+1	-1	+1	7
15	+1	+1	+1	-1	9
16	+1	+1	+1	+1	10

The values of the factors (indicators) are presented in the form of the variable x_{ij} («i» stands for the FFE term associated with the i-th experiment, and "j" stands for the factor (indicator). The FFE plan uses a full range of combinations of factors ($N=2^n=2^4=16$).

$$x_{ij} = \begin{cases} \text{-1, if the value of the j-th indicator} \\ \quad \text{is not used to make a decision} \\ \quad \text{on attack actions in the i-th combination} \\ \quad \text{of factor (indicator) values;} \\ \text{+1, if the value of the j-th indicator} \\ \quad \text{is used to make a decision} \\ \quad \text{on attacking actions in the i-th combination} \\ \quad \text{of factor (indicator) values} \end{cases} \tag{1}$$

Therefore, by conducting virtual experiments, with the help of military experts, it is possible to assess the possible impact of the i-th combination of indicators on the decision to attack with the help of attack drones. The "response" value (y) represents the impact of the values of the indicators on the decision to conduct an attack. It is presented in the rightmost column of the FFE.

Based on the results of the virtual experiment and using the FFE and military experts' estimates, an incomplete quadratic regression dependence can be formed as follows:

$$\begin{aligned} y = {} & b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \\ & +b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + \\ & +b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + \\ & +b_{123}x_1x_2x_3 + b_{124}x_1x_2x_4 + \\ & +b_{234}x_2x_3x_4 + b_{134}x_1x_3x_4 + \\ & +b_{1234}x_1x_2x_3x_4. \end{aligned} \tag{2}$$

Here, the coefficient b_j (j=1,...,4) indicates the influence of the j-th factor (indicator) on the "response" y, and the coefficient, for example, b_{234} indicates the influence of the combination of factors (indicators) x_2, x_3, x_4 on y. Suppose we are interested only in the values of the influence of factors (indicators) on the assessment of enemy activity in a particular air defense zone. Therefore, we select the linear part of the regression.

After performing the calculations related to the use of FFE, we obtain the following

$$y = 5 + 3,5x_1 + 3x_2 + 3,25x_3 + 2,75x_4 \quad (3)$$

Based on the results of the above example, using a virtual experiment and military experts' assessments, the following conclusion can be drawn. The greatest influence on the decision to conduct an attack mission against enemy targets with attack drones in a particular FFE is exerted by the F indicator (accumulation of military equipment), followed by the Q indicator (active enemy movement), and then the P indicator (formation of a military group). Indicator V (engineering works) has the least influence on attack decision-making. Further, after assessing the impact of the indicators on the decision to conduct an attack mission using attack drones, we present the set of indicators in the form of a priority series. For our example, these are: F, Q, P, and V. This series will be used to assess each local military zone in a military conflict where enemy activity is observed.

Therefore, in this section, a set of indicators of enemy activity has been formed that can be used to make decisions on conducting an attack mission by strike drones against enemy targets on the battlefield. A virtual experiment with military expert assessments was conducted to evaluate the impact of the indicators on the decision-making process for an attack mission. This allows us to assess the importance of the indicators and form a priority series that will be used to select relevant military local zones on the battlefield, which will be attacked by a swarm of attack drones in the first place.

4.Selection of actual enemy targets

Continuous monitoring of military conditions on the battlefield with the help of reconnaissance drones allows responding to changes in the situation related to enemy actions and preparing a possible attack mission with a swarm of attack drones. To plan a massive attack, it is necessary to form a set of military local zones (MLZs) in which enemy activity is observed and increased. The number of MLZs containing enemy targets affects the size of the combat potential of the drone swarm and the number of swarm groups directed at enemy targets. The generated indicators (F, Q, P, V) of enemy activity allow us to assess the level of military threat for each i-th MLZs ($i = \overline{1, M}$). Let us present the values of the indicators (F, Q, P, V) in the form of qualitative assessments by military experts, which simplifies the analysis of the level of threats for each LOC in the conflict zone. Let's introduce a linguistic variable y_{ik}, where "i" refers to the i-th MLZ, and "k" refers to the k-th indicator (k=1,...,4). The value of y_{ik} is represented using the letters of the Latin alphabet as follows:

$$y_{ik} = \begin{cases} \text{G – military threat index} \\ \quad \text{threat index is "green"} \\ \quad \text{which means not a very high} \\ \quad \text{military threat;} \\ \text{O – imilitary threat index} \\ \quad \text{threat index is "orange"} \\ \quad \text{which means a high} \\ \quad \text{military threat;} \\ \text{R – military threat index} \\ \quad \text{«red», which means} \\ \quad \text{very high military threat.} \end{cases} \quad (4)$$

Using the value of the linguistic variable y_{ik} and the importance of the indicators (F, Q, P, V) in the form of a priority series, for each i-th MLZ, it is possible to represent the i-th MLZ, considering the enemy's threats, in the form of a "word". For example: O, R, O, G. Then, the entire set of MLZ on the battlefield, taking into account the level of enemy threats, can be represented as a list of "words". For example, the results of monitoring the military situation on the battlefield, using reconnaissance drones, as well as assessments by military experts, made it possible to form a set of ten zones of the MLZ. We create a list of "words" to represent the MLZs, considering their threats in the form of:

1. O, R, O, G	6. R, G, O, G	
2. R, O, G, G	7. G, G, O, R	
3. G, R, O, R	8. O, R, R, G	(5)
4. G, O, O, R	9. G, O, R, O	
5. O, G, R, R	10. R, G, G, R.	

Next, we organize the presented list of MLZs, considering the values of the linguistic variable y_{ik} and the priority of indicators (F, Q, P, V) for each individual i-th MLZ (i=1, 2,...,10). Organizing the set of MLZs will allow us to identify those that need to be considered when planning an attack mission by strike drones. We will use lexicographic ordering (as in a dictionary). After ordering, we obtain the following list of "words" for the set of weapons of mass destruction:

7. G, G, O, R
4. G, O, O, R
9. G, O, R, O
3. G, R, O, R
5. O, G, R, R (6)
1. O, R, O, G
8. O, R, R, G

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10. R, G, G, R
6. R, G, O, G
2. R, O, G, G.

At the beginning of the resulting list of "words" are the MLZs whose targets should be attacked last, and at the end are the actual MLZs whose targets will be attacked first. The most relevant variant of the MLZ for attacking actions is the second variant, in which the values of the indicators (F, Q, P, V): R, O, G, G. The number of MLZs to be used for planning a massive attack by strike drones depends on the ability to create a swarm of drones with the necessary combat capability to defeat enemy targets in the selected MLZs. Therefore, in order to simplify the selection of a set of relevant MLZs for planning an attack mission, it is possible, with the help of military experts, to create a "control word" that takes into account the limited capabilities of creating a swarm of attack drones. For example, military experts set the following "control word": O, O, O, O . Let's place the "control word" in the resulting ordered list of MLZ "words". We get:

7. G, G, O, R
4. G, O, O, R
9. G, O, R, O
3. G, R, O, R
5. O, G, R, R (7)
O, O, O, O
1. O, R, O, G
8. O, R, R, G
10. R, G, G, R
6. R, G, O, G
2. R, O, G, G.

It can be seen that the "control word" was located between 5 and 1 MLZ "words". This means that the set of MLZs (7, 4, 9, 3, 5) will not be used in planning an attack mission of attack drones, taking into account the assessments of military experts on the possibility of creating a swarm of attack drones with the necessary combat potential. The variants of the MLZ (1, 8, 10, 6, 2) will be used to conduct a massive attack by a swarm of attack drones. First of all, this applies to the second MLZ with the performance ratings (F, Q, P, V): R, O, G, G

Therefore, this section analyzes the military threats from each enemy air defense system on the battlefield. The level of enemy threats was represented by a set of indicators (F, Q, P, V) and their values, which were obtained as a result of intelligence and military experts' assessments. To simplify the procedure for selecting a set of airborne targets to be attacked by strike drones, qualitative assessments of military experts were used in the form of linguistic variable values. A lexicographical ordering of the set of MLZs presented in the form of a list of "words" was carried out. This helped identify actual ERWs that will be attacked by attack drones. The use of the "control word", presented with the help of military experts, helped to form a set of relevant ASW targets that would be attacked in the first place, taking into account the limited capabilities of UAVs.

5. Formation of a swarm of imitator drones

Imitation drones are used to distract and deplete enemy military resources. Simulation of the creation of a swarm of simulator drones helps assess the capabilities of enemy anti-drone warfare (ADW), analyze the actions of electronic warfare, and cause overload of air defense. Thus, the flight of simulator drones helps to plan the combat mission of a swarm of attack drones. Before planning the flight of a swarm of simulator drones, it is necessary to identify the locations of the UAVs, EW, and air defense through aerial reconnaissance. This helps to form the required number of simulator drones in the swarm. In the flight of the swarm of simulator drones, it is necessary to divide the swarm into groups that will move to the e-th possible locations of the ABP, EW, and air defense. For each e-th possible location (ASW, EW, air defense), the number of simulator drones (W_e) is required, which will have a significant impact on resource depletion (L_e). However, it is necessary to assess both the limitations of individual drones (flight time and range, flight altitude, etc.) and the limitations on the number of simulator drones to create a swarm. This raises the complex problem of forming a swarm of simulator drones, which is studied in this section. The presented task represents the solution to combinatorial problems with a set of alternative options to choose the rational one. Therefore, we use the method of integer (Boolean) programming, which has proven to be effective in solving optimization problems in various subject areas with a large number of possible options. Let's introduce a Boolean variable x_{ek}, where the index "e" will refer to the e-th location (air defense, electronic warfare, air defense), and the index "k" to the possible composition of the group of simulator drones that will be sent in flight to the e-th location (air defense, electronic warfare, air defense). Let's represent x_{ek} in the form:

$$x_{ek} = \begin{cases} 1, & \text{if to the e-th location} \\ & \text{(BWP, REB, air defense)} \\ & \text{will be directed to the k-th variant} \\ & \text{of a group of simulator drones;} \\ 0, & \text{in the other case.} \end{cases} \quad (8)$$

The following indicators are used to evaluate the effectiveness of a swarm of simulator drones:

1. Number of simulator drones in the swarm:

$$W = \sum_{e=1}^{N}\sum_{k=1}^{n_e} w_{ek}x_{ek} \, . \tag{9}$$

2. The impact of a swarm of simulator drones on resource depletion (air defense, electronic warfare, air defense):

$$L = \sum_{e=1}^{N}\sum_{k=1}^{n_e} l_{ek}x_{ek} \, , \tag{10}$$

where N is the number of possible locations (BOP, REB, air defense);

n_e – the number of possible options for forming a group of swarms of simulator drones for flying to the location (air defense, electronic warfare, air defense);

w_k – the number of simulator drones in the k-th possible swarm group that will be sent to the e-th location (EW, EW, air defense);

l_{ek} – assessment of the impact (in points 0÷10) of the k-th variant of the composition of the group of simulator drones on the depletion of resources located at the e-th location (air defense, electronic warfare, air defense). This requires assessments by military experts.

The following formulations of the optimization problem are possible to ensure the effectiveness of using a swarm of simulator drones before conducting an attack mission using a swarm of strike drones:

1. Maximize the impact of a swarm of imitator drones on the depletion of enemy resources (air defense, electronic warfare, air defense):

$$\max L, \ L = \sum_{e=1}^{N}\sum_{k=1}^{n_e} l_{ek}x_{ek} \, , \tag{11}$$

considering the limited possibilities for creating a swarm of imitator drones:

$$W \le W', \ W = \sum_{e=1}^{N}\sum_{k=1}^{n_e} w_{ek}x_{ek} \, , \tag{12}$$

where W′ – limitation on the number of simulator drones to create a swarm (assessment of military experts).

2. Minimizing the number of simulator drones in the swarm:

$$\min W, \ W = \sum_{e=1}^{N}\sum_{k=1}^{n_e} w_{ek}x_{ek} \, , \tag{13}$$

considering the restrictions on the necessary impact of imitator drones on the depletion of enemy resources (air defense, electronic warfare, air defense):

$$L \ge L', \ L = \sum_{e=1}^{N}\sum_{k=1}^{n_e} l_{ek}x_{ek} \, , \tag{14}$$

where L′ – the planned impact on the depletion of enemy resources (air defense, electronic warfare, air defense), using simulator drones (assessment of military experts).

3. Multi-criteria formulation of the optimization problem.

It is necessary to find a compromise value among contradictory indicators W and L using a complex criterion as follows:

$$Q = \alpha_W \overline{W} + \alpha_L \overline{L}, \tag{15}$$

where α_W, α_L – «weights» of indicators W, L, which military experts assign: $\alpha_W+\alpha_L=1$, $\overline{W}, \overline{L}$ – normalized values of indicators W, L:

$$\overline{W} = \frac{W - W^*}{W' - W^*}, \overline{L} = \frac{L^* - L}{L^* - L'}, \tag{16}$$

where W*, L* – optimal values of W, L indicators obtained after their optimization.

It is necessary to minimize the complex indicator Q, which helps to create a compromise among the indicators W, L as follows:

$$\min Q, \ Q = \alpha_W \frac{W - W^*}{W' - W^*} + \alpha_L \frac{L^* - L}{L^* - L'}. \tag{17}$$

Therefore, in this section, the task of forming a swarm of simulator drones to be used before conducting an attack mission by a swarm of strike drones was set and solved. The main indicators for assessing the effectiveness of using a swarm of imitator drones were as follows:

- number of simulator drones required to form a swarm;
- the impact of a swarm of imitator drones on the depletion of enemy resources (air defense, electronic warfare, air defense).

Given that the presented problem is combinatorial in nature, with several possible options, the method of integer (Boolean) programming was used to solve it. The following possible formulations of optimization problems are presented:

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- maximizing the impact of a swarm of imitator drones on the depletion of enemy resources (air defense, electronic warfare, air defense);

- minimizing the number of imitator drones, considering the limited capabilities to create a swarm;

- finding a compromise among the contradictory indicators of the number of imitator drones and their impact on the depletion of enemy resources (air defense, electronic warfare, air defense).

6. Creating a combat potential of an attack drone swarm

The analysis of intelligence data collected by reconnaissance drones, as well as the results of the actions of simulator drones, allows us to identify and form relevant targets in military local zones that need to be destroyed by a swarm of attack drones. However, for this purpose, it is necessary to establish an adequate combat capability for attack drones that is capable of destroying enemy targets. An analysis of the enemy targets to be attacked (control points, military equipment, etc.) allows us to assess the required combat capability of attack drones to destroy each individual target. Here, it is necessary to take into account the limitations associated with the capabilities of individual attack drones (payload, flight time and range, size of the affected area, etc.), as well as the number of attack drones to form a swarm. Therefore, there is a combinatorial task associated with the formation and analysis of a set of options for dividing a swarm of drones into groups that move to separate targets (or groups of targets) of the enemy in the selected AOR to conduct an attack. To solve this problem, we will use the method of integer (Boolean) programming. Let's introduce a Boolean variable y_{iep}, which has the following values:

$$y_{iep} = \begin{cases} 1, \text{ if the p-th attack drone} \\ \text{ of the swarm is directed at the} \\ \text{ e-th target in the i-th MLZ;} \\ 0, \text{ other cases.} \end{cases} \quad (18)$$

To evaluate the effectiveness of forming swarm groups to be sent to individual MLZs, according to the enemy's current targets, we introduce the following indicators and restrictions:

- combat potential of a swarm of drones (A′);

- combat capability necessary to inflict damage on the enemy (up to complete defeat) (A′′);

- combat capability of a group of strike drones, formed to defeat targets in the i-th MLZ (A_i');

- combat potential of attack drones, which is necessary to inflict damage to the enemy in the i-th MLZ (A_i'');

- is the size of the damage predicted after the attack by the strike drones in the i-th MLZ (B_i);

- the importance of defeating targets in the i-th MLZ for successful military operations on the battlefield (α_i):

$$\sum_{i=1}^{M} \alpha_i = 1 .$$

Considering the Boolean variable y_{iep}, we present an optimization problem for the formation of the combat potential of attack drones to conduct an attack mission against enemy targets:

$$A_i' = \sum_{e=1}^{m_i} \sum_{p=1}^{N} a_p y_{iep}, \quad (19)$$

$$A' = \sum_{i=1}^{M} A_i', \; A'' = \sum_{i=1}^{M} A_i'',$$

$$B = \sum_{i=1}^{M} B_i, B_i = \sum_{e=1}^{m_i} \sum_{p=1}^{N} b_p y_{iep} . \quad (20)$$

It is necessary to: A′>A′′, $A_i' \geq A_i''$, $\sum_{i=1}^{M} \sum_{e=1}^{m_i} y_{iep} = 1$,

for each and every $p = \overline{1, N}$, which is associated with the mandatory use of the p-th strike drone in an attack mission;

a_p – combat capability of the r-th strike drone;

b_p – the amount of damage to the enemy from the actions of the p-th attack drone;

N – number of attack drones in the swarm;

M – the number of MLZs on the battlefield;

m_i – is the number of enemy targets in the i-th MLZ.

These formulations of the optimization problem are possible:

1. To maximize the damage to the enemy after an attack mission by a swarm of attack drones:

$$\begin{aligned} &\max B, \; B = B_1 + B_2 + ... + B_M = \\ &= \alpha_1 \sum_{e=1}^{m_1} \sum_{p=1}^{N} b_p y_{1ep} + \\ &+ \alpha_2 \sum_{e=1}^{m_2} \sum_{p=1}^{N} b_p y_{2ep} + ... + \\ &+ \alpha_M \sum_{e=1}^{m_M} \sum_{p=1}^{N} b_p y_{Mep}, \end{aligned} \quad (21)$$

subject to limitations:

$$A' > A'',\ A_i' \geq A_i'',$$

$$A_i' = \sum_{e=1}^{m_i}\sum_{p=1}^{N} a_p y_{iep}, \quad (22)$$

$$\sum_{i=1}^{M}\sum_{e=1}^{m_i} y_{iep} = 1, \text{ for all } p = \overline{1,N}.$$

2. Maximizing the combat potential of attack drones:

$$\max A,\ A = \alpha_1 \sum_{e=1}^{m_1}\sum_{p=1}^{N} a_p y_{1ep} + \\ + \alpha_2 \sum_{e=1}^{m_2}\sum_{p=1}^{N} a_2 y_{2ep} + \ldots + \\ + \alpha_M \sum_{e=1}^{m_M}\sum_{p=1}^{N} a_p y_{Mep}, \quad (23)$$

subject to limitations:

$$B > B',\ B_i \geq B_i',$$

$$B = \sum_{i=1}^{M} B_i,\ B_i = \sum_{e=1}^{m_i}\sum_{p=1}^{N} b_p y_{iep} \quad i = \overline{1,M}, \quad (24)$$

$$\sum_{i=1}^{M}\sum_{e=1}^{m_1} y_{iep} = 1,\ p = \overline{1,N},$$

where B' – planned harm to the enemy;

B_i' – is the planned damage to the enemy in the i-th MLZ.

To solve optimization problems using integer (Boolean) programming, you can use [30]:

- full search method for a relatively small number of options;
- a modified branch and constraints method in the case of many options;
- a random search method for a vast number of options. This does not guarantee an extremum search, but allows the value of the indicator (for example, as a percentage).

Therefore, this section formulates and solves the problem of forming a swarm of attack drones and dividing it into groups aimed at enemy targets in the current conflict zone. This takes into account the limitations on the combat potential of individual drones, the number of attack drones in the swarm, and the damage that occurs to the enemy when conducting an attack mission with a swarm of attack drones. The method of integer (Boolean) programming is used to solve this problem. The main indicators and constraints are formed. The formulation of the optimization problem is as follows:

- maximizing the enemy's damage when conducting an attack mission with attack drones;
- maximization of the combat potential of attack drones to ensure the success of the attack mission with the help of a swarm of attack drones.

7. Formation of waves of attack drone swarms

An attack by a swarm of attack drones should result in damage to the enemy; however, anti-drone actions do not allow for complete destruction of enemy targets (or maximum damage). Therefore, there is a need to plan multiple waves of a swarm of attack drones. After each s-th wave, using attack drones, it is necessary to assess the results of the attack (the degree of damage to targets) through reconnaissance actions (reconnaissance drones) and create the combat potential of the drone swarm necessary to form the (s+1) wave for further defeat of enemy targets. It is necessary to form a combat capability in (s+1) waves of a drone swarm (A_{s+1}') in such a way that $A_{s+1}' > A_s''$, where A_s'' – combat capability required to defeat enemy targets after the s-th wave attack. The task is to create the combat potential of attack drones for a new wave of attack actions and their rational distribution over all relevant WLZs. The number of swarm waves depends on the restrictions on their creation and the need to increase the amount of enemy losses ($A_s'' \to 0$, $A_{is}'' \to 0$).

Therefore, the task arises of forming the necessary combat potential of attack drones and its distribution according to the actual goals, in separate WLZs for each wave of attack drones. To solve this problem, we will use the results of Section 6.

1. It is necessary to maximize the damage to the enemy with the help of (s+1) waves of attack drone swarms:

$$\max B_{s+1},\ B_{s+1} = B_{1(s+1)} + B_{2(s+1)} + \ldots + B_{M(s+1)} = \\ = \alpha_{1(s+1)} \sum_{e=1}^{m_{1(s+1)}}\sum_{p=1}^{N_{(s+1)}} b_p y_{1ep} + \\ + \alpha_{2(s+1)} \sum_{e=1}^{m_{2(s+1)}}\sum_{p=1}^{N_{(s+1)}} b_p y_{2ep} + \ldots + \\ + \alpha_{M(s+1)} \sum_{e=1}^{m_{M(s+1)}}\sum_{p=1}^{N_{(s+1)}} b_p y_{M(s+1)ep}, \quad (25)$$

subject to limitations:

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$$A_{(s+1)}' > A_s'',\ A_{i(s+1)}' \geq A_{is}'',$$

$$A_{i(s+1)}' = \sum_{e=1}^{m_{i(s+1)}} \sum_{p=1}^{N_{(s+1)}} a_p y_{i(s+1)ep},\quad i = \overline{1, M_{(s+1)}}, \qquad (26)$$

$$\sum_{i=1}^{M_{(s+1)}} \sum_{e=1}^{m_{i(s+1)}} y_{i(s+1)ep} = 1,$$

where N_{s+1} – the number of drones allocated to the military to form a swarm of attack drones in the (s+1) wave;

M_{s+1} – is the set of actual MLZs whose targets are to be attacked (s+1) by a wave of swarms of attack drones;

$m_{i(s+1)}$ – is the set of targets in the i-th LOC that must be destroyed after (s+1) attacks by attack drones.

2. It is necessary to maximize the combat potential of attack drones in the (s+1) wave:

$$\max A_{(s+1)}',\ A_{(s+1)}' = \alpha_{1(s+1)} \sum_{e=1}^{m_{1(s+1)}} \sum_{p=1}^{N_{(s+1)}} a_p y_{1ep} + \alpha_{2(s+1)} \sum_{e=1}^{m_{2(s+1)}} \sum_{p=1}^{N_{(s+1)}} a_p y_{2ep} + \ldots + \alpha_{M(s+1)} \sum_{e=1}^{m_{M(s+1)}} \sum_{p=1}^{N_{(s+1)}} a_p y_{M(s+1)ep}, \qquad (27)$$

subject to limitations:

$$B_{(s+1)}' > B_s'',\ B_{i(s+1)}' \geq B_{is}'',$$

$$B_{i(s+1)}' = \sum_{e=1}^{m_{i(s+1)}} \sum_{p=1}^{N_{(s+1)}} b_p y_{i(s+1)ep},\ i = \overline{1, M_{(s+1)}}, \qquad (28)$$

$$\sum_{i=1}^{M} \sum_{e=1}^{m_1} y_{iep} = 1 \ \text{ for all } \ p = \overline{1, N_{(s+1)}}.$$

Therefore, this section sets and solves the problem of planning a set of waves of a swarm of attack drones to maximize the defeat of enemy targets on the battlefield. This affects the reduction of enemy combat activity and contributes to the success of further combat operations. For each wave of attack drones, the necessary potential is formed to conduct an attack, and the rational distribution of drones to actual targets in separate MLZ is carried out. The method of integer (Boolean) programming is used to form the composition of a swarm of attack drones and its rational distribution, taking into account the combat potential of drones, for actual targets in individual MLZ.

8. A multi-agent simulation model of the swarm movement of the attack drones

The study of the dynamic process of attack drones' movement on a given time scale allows us to form swarm flight routes in each wave of the attack mission. Obstacles to this process arise in the form of enemy military threats (anti-drone operations, electronic warfare, air defense systems, etc.). Therefore, it is necessary to form a set of relatively safe flight zones on the aerial map of the battlefield to ensure a successful mission of attack drones, with minimal risks of enemy military threats. To study the dynamic process of drone swarm movement, we used a simulation modeling method involving an agent platform Any Logic [31]. In this study, simulation modeling was used to plan the flight routes as follows:

- reconnaissance drones
- simulator drones;
- attack drones.

The main phases of the flight of a swarm of attack drones were modeled (swarm formation, swarm flight, swarm division into groups, flight of groups of attack drones to targets, etc.).

The enemy's anti-drone actions were modeled to affect the movement and partial destruction of attack drones. A set of agents was formed to study the peculiarities of wave attack planning by attack drones despite enemy military threats. The agents include the following:

1. The agent of “mapping the air situation”.
2. Agent “formation of a swarm of attack drones”.
3. Agent for “formation of launch sites for attack drones”.
4. Agent “formation of enemy target locations”.
5. Agent “setting the flight route”.
6. Agent “flight route optimization”.
7. Agent “setting navigation points for dividing the swarm into groups”.
8. Agent “emergence of enemy threats”.
9. Agent “destruction of drones due to enemy actions”.
10. Agent “level of damage to enemy targets”.
11. Agent “interactive control of modeling”.
12. Agent “modeling results”.

Fig. 2 shows a block diagram of a multiagent model.

Based on the study of the dynamic process of flying a swarm of attack drones, the following results were obtained using simulation modeling:

- the number of attack drones in the swarm;
- the number of destroyed enemy targets;

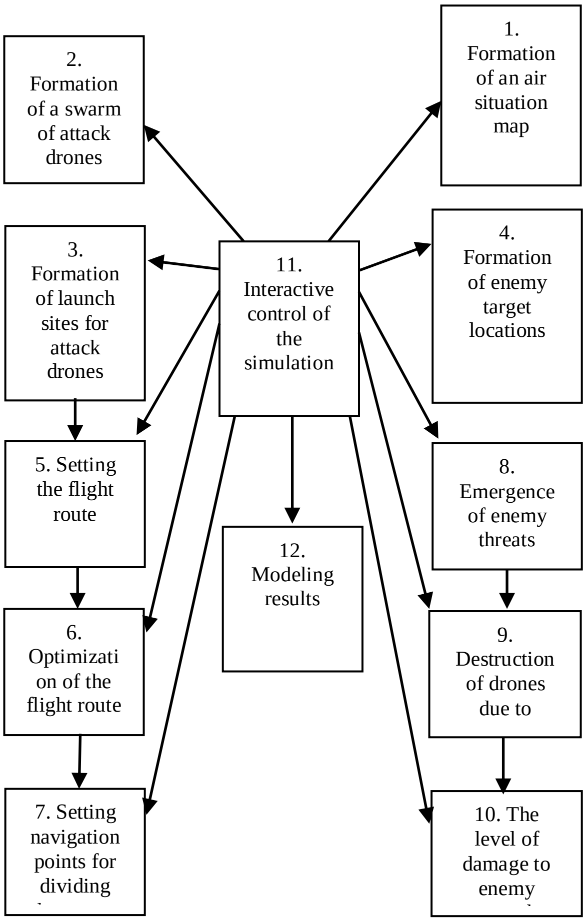

Fig. 2. Block diagram
of the multi-agent model

- flight time of a swarm of attack drones directed at enemy targets;
- flight routes of individual drones;
- the appearance of enemy military threats (time and number);
- number of defeated drones (due to enemy actions).

Based on the results of simulation modeling of a massive attack by attack drones, a decision is made to plan a new wave of attacks, depending on the level of damage to enemy targets and decisions made by the military.

Therefore, in this section, the dynamic flight process of a swarm of attack drones to enemy targets is investigated. Simulation modeling was used to study in detail the movement of drones in time on a map of the air conditions on a battlefield. The main actions associated with the formation of a swarm, flight of the swarm to the targets, division of the swarm into groups, and defeat of enemy targets are investigated. The simulation model was implemented using the Any Logic agent platform.

9. An example of modeling an attack by attack drones

Let us consider an example of using the proposed approach to model an attack mission using a swarm of attack drones. In Section 3, we substantiated the indicators for assessing enemy activity, which, in Section 4, are used to estimate the set of military logistics zones (MLZs) on the battlefield. An example is presented of the selection of relevant MLZs whose targets will be attacked by attack drones. This example serves as the basis for further calculations in this section, necessary for planning the attack mission.

Let's select a set of imitator drones to distract and deplete enemy resources (ASW, EW, and air defense) (see Section 5).

Suppose that, because of intelligence, the enemy has identified the following means of anti-drone warfare (ASW, EW, air defense) in the amount of:

1. The number of PBP means 2.
2. REB means - quantity 3.
3. Air defense equipment - number 2.

The intelligence revealed that the assets were located in 4 locations in the conflict zone:

1st place: PBB - 1, AIR DEFENSE - 1.
2nd place: PBP - 1, REB - 1.
3rd place: REB - 1, PPO - 1.
4th place: REB - 1.

To distract and deplete the enemy's resources, it is necessary to allocate (according to the military):

- 2 simulator drones for the PBP;
- for electronic warfare - 1 simulator drone;
- for air defense - 3 simulator drones.

Taking into account the locations and anti-drone capabilities available there, the following number of simulator drones is required:

1st place: 5 simulator drones.
2nd place: 3 simulator drones.
3rd place: 4 simulator drones.
4th place: 1 imitator drone.

Thus, to distract and deplete the enemy's resources, 5+3+4+1=13 imitator drones are necessary.

However, due to limited capacity to allocate simulator drones, there are P=8 simulator drones available, which were allocated to the military. This is not enough. Therefore, the task arises of rationally dividing simulator drones into groups that will be sent in flight to locations (air defense, electronic warfare, enemy air defense) under the conditions of a limited number of simulator drones (P=8, 13>8). The number of variants of the composition of places that will be used in flight by imitator drones to distract and deplete resources can be estimated by the formula: $N=2^m-1$, m=4. All possible variants of the location composition (EW, EW, air defense) are presented in Table 2. For

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each variant of the composition of locations (ASW, EW, ASW), the required number of simulator drones is presented in Table 2. Further, using the limited number of simulator drones (P=8), it was noted that there are options with the number of simulator drones that cannot be used (the required number is more than 8). The options are: 11, 13, 14, 15. Therefore, Table 3 was compiled with options for the composition of locations (air defense, electronic warfare, air defense) that can be used to fly a swarm of imitator drones to conduct distractions and deplete enemy resources. Military experts have prioritized, at points (0÷10), the locations (air defense, electronic warfare, air defense) that are determined by various enemy activities for the use of anti-drone actions.

Table 2

Options for selecting the composition of places location of the BOP, RBM, and air defense

№	1	2	3	4	Number of simulator drones
1	0	0	0	1	1
2	0	0	1	0	4
3	0	0	1	1	5
4	0	1	0	0	3
5	0	1	0	1	4
6	0	1	1	0	7
7	0	1	1	1	8
8	1	0	0	0	5
9	1	0	0	1	6
10	1	0	1	0	8
11	1	0	1	1	10
12	1	1	0	0	8
13	1	1	0	1	9
14	1	1	1	0	12
15	1	1	1	1	13

Let's present the importance of each location (ASW, EW, air defense) for launching simulator drones with a point system (with the help of military experts):

1st place - 2 points;
2nd place - 4 points;
3rd place - 1 point;
4th place - 3 points.

Table 3 presents the total number of points for each possible variant of the composition of locations (ASW, EW, air defense). The seventh option has the highest number of points, in which the flight of a swarm of simulator drones uses locations 2, 3, and 4 (ASW, EW, air defense). Let's divide the swarm of simulator drones into three groups. The first group will be directed to the second location (ASW, EW, air defense) and will use three simulator drones. The second group of simulator drones will be aimed at the third location (ASW, EW, air defense) using four simulator drones. The third group, in the form of one simulator drone, will be aimed at the fourth location (ASW, EW, air defense) of the enemy.

Table 3

Options for location composition ASW, EW, AIR DEFENSE

№	1	2	3	4	Number of simulator drones	Total number of points
1	0	0	0	1	1	3
2	0	0	1	0	4	1
3	0	0	1	1	5	4
4	0	1	0	0	3	4
5	0	1	0	1	4	7
6	0	1	1	0	7	5
7	0	1	1	1	8	8
8	1	0	0	0	5	2
9	1	0	0	1	6	5
10	1	0	1	0	8	3
12	1	1	0	0	8	6

Next, we present an example of forming and dividing a swarm of attack drones into groups to plan attacks against actual enemy targets in military localized areas (MLZs) of the conflict. In the fourth section, the author substantiates the set of MLZs whose targets will be attacked by attack drones in the first place. The following relevant MLZs were identified for attack, which have increased enemy activity:

1. O, R, O, G
8. O, R, R, G
10. R, G, G, R
6. R, G, O, G
2. R, O, G, G.

This example is used later to justify a swarm of attack drones in the planning of an attack mission (see Section 6).

Suppose that, using the results of intelligence as well as the analysis of military experts, the necessary combat potential to defeat enemy targets in each MLZ can be estimated in the form of the explosive amount in kg:

A_1''=10 kg;
A_8''=20 kg;
A_{10}''=40 kg;
A_6''=45 kg;
A_2''=50 kg.

Total combat capability to engage targets in the entire set of MLZ:

$$A''=10+20+40+45+50=165 \text{ kg}.$$

To conduct an attack mission with the help of a swarm of attack drones, it is possible to allocate only 7 identical attack UAVs, each with a payload of 15 kg of explosives. The total combat potential for the planned swarm of attack drones for an attack mission will be: A'=105 kg BP. This is not enough to fulfill the conditions for complete destruction of enemy targets ($A' \geq A''$), because in our case $A' < A''$ (see Section 6). Therefore, the task arises of distributing the available combat potential of attack drones to the i-th MLZs (1, 8, 6, 2) so that $A_i' \geq A_i''$. To plan the attack, a set of possible compositions of the MLZ was formed for further analysis. The number of variants in the composition of the medical supplies was calculated using the formula: $N=2^n-1=2^5-1=31$ variant. The formation of possible variants of the composition of airborne weapons for attack drones was carried out using a binary counter. Table 4 presents the formed set of possible compositions of airborne weapons.

For each j-th possible variant of the composition of the MLZ, the required combat capability was calculated A_j'' to defeat enemy targets, so that $A_j' \geq A_j''$. Table 4 lists the required number of drones for each possible variant of the airborne force composition. The analysis in Table 4 shows that there are options for which there is no available combat capability due to limitations associated with the allocated number of attack drones ($A_j' < A_j''$). Therefore, these options are not considered in the attack mission planning. These are options: 7, 11, 13, 15, 23, 27, 29, 30, 31. Therefore, Table 5 was formed to assess the defeat of enemy targets, depending on the j-th composition of the MLZ and the available total combat potential of attack drones.

The analysis showed that the maximum percentage (64%) of enemy targets was hit by variants 14 and 19 of the MLZ composition. Taking into account the formed priority of the MLZs selected for attack (see Section 4), with the help of military experts, the 19th variant was selected, for which the following conditions are met $A_{19}' \geq A_{19}''$ (A_{19}'=7x15=105 kg BP, A_{19}''=105 kg BP). When planning an attack mission for a swarm of attack drones, it is necessary to divide the swarm into three groups in flight. The first group, consisting of one attack drone, is directed at attacking the first MLZ, the second group, consisting of three attack drones, is directed at the sixth MLZ, and the third group, consisting of three drones, is directed at the second MLZ.

The results of planning a massive attack with attack drones indicate that the enemy targets were incompletely defeated; therefore, it is necessary to conduct a simulation to plan a new attack wave using the calculation scheme presented in this section. Simulation modeling of the dynamic process of a massive attack by attack drones (see Section 8) will allow for a more accurate assessment of the results of an attack mission.

Table 4

The set of possible compositions of MLZ

№	MLZ					Required combat capabilities	The required number of drones
	1	8	10	6	2		
1	0	0	0	0	1	50	4
2	0	0	0	1	0	45	3
3	0	0	0	1	1	95	7
4	0	0	1	0	0	40	3
5	0	0	1	0	1	90	6
6	0	0	1	1	0	85	6
7	0	0	1	1	1	135	9
8	0	1	0	0	0	20	2
9	0	1	0	0	1	70	5
10	0	1	0	1	0	65	5
11	0	1	0	1	1	115	8
12	0	1	1	0	0	60	4
13	0	1	1	0	1	110	8
14	0	1	1	1	0	105	7
15	0	1	1	1	1	155	11
16	1	0	0	0	0	10	1
17	1	0	0	0	1	60	4
18	1	0	0	1	0	55	4
19	1	0	0	1	1	105	7
20	1	0	1	0	0	50	4
21	1	0	1	0	1	100	7
22	1	0	1	1	0	95	7
23	1	0	1	1	1	145	10
24	1	1	0	0	0	30	2
25	1	1	0	0	1	80	6
26	1	1	0	1	0	75	5
27	1	1	0	1	1	125	9
28	1	1	1	0	0	70	5
29	1	1	1	0	1	120	8
30	1	1	1	1	0	115	8
31	1	1	1	1	1	165	11

Therefore, this section provides an illustrated example of the use of the developed approach,

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demonstrating its effectiveness and practical significance for the military to use a swarm of attack drones to create an active air shield on the battlefield.

Table 5

Defeating of enemy targets

№	Variants for composition of MLZ					Assessment of incidence, (%)
	1	8	10	6	2	
1	0	0	0	0	1	30
2	0	0	0	1	0	27
3	0	0	0	1	1	58
4	0	0	1	0	0	24
5	0	0	1	0	1	55
6	0	0	1	1	0	52
8	0	1	0	0	0	12
9	0	1	0	0	1	42
10	0	1	0	1	0	39
12	0	1	1	0	0	36
14	0	1	1	1	0	64
16	1	0	0	0	0	6
17	1	0	0	0	1	36
18	1	0	0	1	0	33
19	1	0	0	1	1	64
20	1	0	1	0	0	30
21	1	0	1	0	1	60
22	1	0	1	1	0	58
24	1	1	0	0	0	18
25	1	1	0	0	1	48
26	1	1	0	1	0	45
28	1	1	1	0	0	42

10. Discussion

A systematic representation of the sequence of military actions for planning an attack mission using a swarm of attack drones was created. The battlefield circumstances were analyzed using reconnaissance drones. Military local zones were formed in which enemy activity was observed. To form a set of military local zones (MLZs) in conditions of limited opportunities to create a swarm of attack drones, the indicators of enemy activity are substantiated. The set of relevant MLZs, the targets of which will be attacked by attack drones, is identified by using the lexicographic ordering of options and qualitative assessments of experts. The number of imitator drones to conduct distractions and deplete enemy military resources was also substantiated. The combat potential of attack drones during an attacking mission was optimized, in conditions of limited ability to create a swarm. Using the analysis of the results of combat operations (the degree of damage to enemy targets) conducted with the help of a swarm of attack drones, a new wave of attack drones is formed. The number of waves depends on the military's plans and the limitations of creating a drone swarm. To simulate, on a given time scale, the flight of a swarm of attack drones, we used simulation of the movement of drones to enemy targets using the Any Logic agent platform.

The following research methodology is proposed:

- analysis of the circumstances at the battlefield using reconnaissance drones;
- the formation of indicators to assess the enemy's activity in the military local zones (MLZ) of the conflict;
- identification of relevant MLZs that will be attacked by a swarm of attack drones in conditions of limited capabilities;
- forming a swarm of imitator drones to distract and deplete enemy military resources;
- creation of the necessary combat potential of a swarm of attack drones to defeat the enemy's current targets;
- forming the required number of waves of attacking drones to inflict maximum damage on the enemy;
- modeling the flight movements of a swarm of attack drones despite military threats.

The relevance of the proposed approach is related to the need for scientific justification of the use of a new innovative technological tool of war, in the form of a set of different types of drones (reconnaissance drones, simulator drones, attack drones) to conduct an attack mission against enemy targets to assist the military on the battlefield.

The developed set of models is aimed at planning attack missions by drones despite enemy military threats. This allows us to conclude that the proposed approach is timely and effective for integrating combat operations both in air and on ground.

Future research will focus on improving applied information technology for modeling military operations for conducting an attack mission by a swarm of attack drones, which will contribute to the creation of an active air shield for the military on battlefields.

11. Conclusions

The conducted research allows us to plan an attack mission with the help of UAVs, using reconnaissance drones, simulator drones, and attack drones, namely

- forming a strategy for planning the sequence of military actions during an attack mission;
- to justify military local zones on the battlefield for attacking enemy targets;
- assessing the enemy's activity to develop actual targets to be attacked;
- to assess the effectiveness of the use of imitator

drones to conduct distractions and deplete enemy military resources before conducting a massive attack;

- to form the necessary combat potential of a swarm of attack drones to defeat the enemy's current targets;
- to form the required number of attack waves to inflict maximum damage on the enemy;
- to plan the movements of drones (reconnaissance drones, imitation drones, and attack drones) despite military threats.

The combined use of qualitative and quantitative assessments allows for the planning of a drone swarm attack under conditions of limited capabilities (number of drones, combat potential). Limited capabilities (quantitative and qualitative indicators) are the main factor used in the work to assess the effectiveness of an attack mission using a swarm of attack drones.

The scientific novelty of the study is related to the creation of new and original models that can substantiate the sequence of military actions to plan the attack mission of a swarm of attack drones in conditions of limited capabilities.

Thus, the main contribution of this study is as follows:

The proposed set of models allows us to substantiate the sequence of combat operations with the help of a swarm of attack drones; to substantiate military local zones for an attack mission, taking into account the enemy's activity; to form the necessary set of imitator drones to conduct distractions and deplete the enemy's resources; to substantiate the combat potential of a swarm of attack drones; and to estimate the required number of attack waves under the conditions of enemy anti-drone actions.

This will ensure the effectiveness of using attack drones to create an active air shield to support the military on battlefields.

Contribution of authors: system analysis of the sequence of military actions for planning an attack mission by a swarm of attack drones **- O. Fedorovych**; formation of a swarm of simulator drones **- D. Krytskyi**; formation of actual military local zones for attacking with attack drones **- A. Popov**; modeling of attack waves by attack drones **- O. Gubka**

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.

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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.

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МОДЕЛЮВАННЯ ПОСЛІДОВНОСТІ ВІЙСЬКОВИХ ДІЙ ЩОДО ПЛАНУВАННЯ АТАКУЮЧОЇ МІСІЇ РОЮ УДАРНИХ ДРОНІВ

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Використання безпілотних літальних апаратів (БПЛА) стало інноваційним технологічним інструментом сучасної гібридної війни. Ефективність застосування БПЛА різко зросло при згортанні бойових дронів у рій для проведення атакуючих дій за цілями противника. Створення активного щита у повітрі, для допомоги військовим на землі, дозволяє інтегрувати повітряні та наземні бойові дії, що дає новий синергетичний ефект від застосування ударних дронів. Тому, **актуально** проведення дослідження щодо планування атакуючих місій, за допомогою ударних БПЛА. **Предметом** дослідження є моделі, які використовуються для планування атакуючих військових дій з використанням ударних дронів. **Метою** є створення комплексу моделей, який дозволяє планувати масовані атаки ударних дронів. **Завдання**, які необхідно вирішити: сформувати послідовність військових дій для проведення атакуючої місії; обґрунтувати вибір локальних військових зон для атаки; сформувати бойовий потенціал рою дронів; обґрунтувати використання дронів-імітаторів для виснаження ресурсів противника; сформувати хвилі рою ударних дронів; промоделювати рух рою до цілей. Використані математичні **методи та моделі**: системний аналіз, для формування атакуючої місії ударних дронів; метод віртуального експерименту, для вибору важливих показників оцінки активності противника; метод якісного оцінювання дій противника; метод лексикографічного впорядковування варіантів, для вибору актуальних військових локальних зон для атаки; цілочисельна (булева) оптимізація для створення необхідного бойового потенціалу ураження цілей противника; імітаційне мультиагентне моделювання польоту рою ударних дронів. Отримані наступні **результати**: отримано системне представлення послідовності військових дій для проведення атаки ударними дронами; обґрунтовані показники активності противника; сформована множина актуальних військових локальних зон с цілями противника; проведене створення рою дронів-імітаторів для відволікання противника; сформовано необхідний бойовий потенціал рою атакуючих дронів; обґрунтовані хвилі ударних дронів для ураження цілей противника; створена імітаційна, мультиагентна модель руху рою. **Висновки**. Результати проведеного дослідження дозволяють обґрунтувати план бойових дій з використанням рою ударних дронів, що сприяє ефективності проведення оперативно-тактичних дій на полі бою. **Новизна** запропонованого підходу полягає в науковому обґрунтуванні послідовності військових дій щодо планування атакуючої місії ударних дронів, з використанням розробленого комплексу оригінальних та нових математичних та імітаційної моделей.

Ключові слова: рій ударних дронів; хвильова атака дронами; множина локальних військових зон з актуальними цілями; показники оцінки активності противника; оптимізація бойового потенціалу рою ударних дронів; імітаційне та агентне моделювання військових дій; хвильова атака ударними дронами.

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