UDC 005.963.1:629.7.-027.3 **doi: 10.32620/aktt.2025.2.08**

**Oleg FEDOROVYCH, Leonid MALIEIEV, Oleksii HUBKA, Andrei POPOV**

***National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine***

# MODELING OF PROJECT ACTIVITIES FOR UAV MODERNIZATION TO CONDUCT SWARM DRONE ATTACK MISSIONS

*This study addresses the critical issue of modernizing existing unmanned aerial vehicles (UAVs) to enhance their applicability in the contemporary conditions of hybrid warfare. The research focuses on adapting the structural design of UAVs through reengineering, enabling their deployment in swarm attack operations against high-priority enemy targets. Thus, this publication explores the essential measures for planning project activities related to UAV modernization, aiming to align their capabilities with the operational needs of military forces on the battlefield. The primary objective of this study is to develop a comprehensive set of mathematical and simulation models that facilitate the planning of UAV modernization projects. The models are intended to optimize new functions related to control, coordination, and navigation, enabling UAVs to perform as part of drone swarms in military missions. This research analyzes the existing challenges in reengineering high-tech systems for evolving operational environments and presents possible UAV reengineering strategies. A particular emphasis is placed on the component-based approach to designing new UAVs or upgrading existing ones. The study categorizes UAV components into three types within the architecture of modern high-tech systems: existing components, components requiring modernization, and newly developed components. The findings highlight the necessity of balancing the reuse of existing components with the integration of innovative technologies. While innovative components enhance UAV capabilities, they also increase project duration, costs, and associated risks – factors that are particularly critical during a state of war. This study also examines the currently deployed UAV models to assess their suitability for modernization projects. In the initial stages of UAV modernization, expert assessments from specialists in complex system manufacturing and military operations are used to evaluate and rank potential modernization options. These qualitative evaluations, represented as linguistic variables, were processed using the lexicographic ordering of alternatives to identify the most reasonable option for implementation. Integrating new components into existing UAV architectures necessitates optimizing reengineering decisions under constraints such as limited time, budget, and heightened risks due to national security conditions. To address this, an optimization model based on integer (Boolean) programming was developed for selecting the most rational UAV component architecture. Additionally, significant attention is given to structuring the sequence of project activities, estimating the project completion time, and evaluating the risks associated with UAV modernization. A simulation model was constructed to analyze the lifecycle of new UAV components or the modernization of existing ones within a specified time scale. The entire modernization project was also simulated to assess the feasibility and efficiency. Using the agent-based platform **AnyLogic**, interactive simulation modeling of the UAV modernization processes was conducted. The scientific novelty of this research lies in the development of original models that enable comprehensive UAV analysis for modernization. These models facilitate the selection of new UAV components, assess modernization project timelines and risks, and apply simulation modeling to evaluate the sequence of project activities. The research findings provide a foundation for planning UAV modernization processes to enhance their operational effectiveness in modern hybrid warfare. By integrating aerial operations with ground-based military actions, this approach contributes to strengthening national defense capabilities.*

***Keywords:*** *Modernization of UAVs; strategies; system analysis; multiple options; component design; lexicographic ordering; mathematical models; simulation modeling; project activities; and multi-criteria optimization.*

## 1. Introduction

During military operations, various types and models of UAVs are employed to support ground forces through reconnaissance, target designation, and offensive actions [1]. However, existing military drones lack the capability to effectively form coordinated swarms [2]. The integration of different types of drones into a unified system enhances operational efficiency, providing a synergistic effect that is crucial in modern hybrid warfare. This integration represents an innovative approach in military conflicts, enabling new strategic advantages [3]. The effectiveness of UAVs significantly increases when they operate in swarm formations or coordinated groups, enabling them to move towards dispersed enemy targets and execute massive wave-

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

based attacks [4]. However, this approach introduces complexities in managing and coordinating individual UAVs within a swarm, requiring advanced communication, decision-making, and control mechanisms. Addressing these challenges necessitates the development of new UAV designs capable of swarm formation and executing combat missions with enhanced control and coordination functionalities, including artificial intelligence (AI)-based decision-making [5]. Consequently, the urgent need arises to either develop new-generation UAVs or modernize existing models, especially under the constraints of a national state of emergency, to ensure their effective deployment on the battlefield.

### 1.1. Motivation

Under conditions of martial law, the development of projects for the creation or modernization of existing UAVs is of critical importance, particularly when these UAVs are expected to perform new functions in combat operations. Practical experience has demonstrated that modernizing existing military equipment – such as upgrading high-explosive aerial bombs and developing guided bomb units (GBU) – significantly reduces design time, production preparation, and the transition to mass production [6]. This, in turn, enhances the combat effectiveness of military forces that extensively deploy drones for battlefield operations. When planning UAV modernization initiatives, it is essential to establish, at the early stages, a new architecture for the unmanned system based on existing UAV platforms. This upgraded architecture should enable advanced control and coordination functions, facilitating the deployment of drone swarms for targeted combat missions [7]. The integration of new components into UAV structures requires a comprehensive project reengineering cycle, which can have a significant impact on the key performance indicators of the UAV modernization project [8]. This study addresses the urgent task of modeling project activities related to UAV modernization while considering the need to minimize project execution time, costs, and risks – especially in the context of national security and emergency conditions.

### 1.2. State of the Art and problem statement

There are several challenges associated with the modernization of UAVs to ensure their effective deployment in the context of modern hybrid warfare [9]. While some of these challenges have been partially addressed, new issues continue to emerge, necessitating further research to expand UAV capabilities for military missions. These include swarm formation and coordinated drone group operations, large-scale offensive actions using UAVs, and wave-based attack strategies. Addressing these challenges requires dedicated studies focused on:

1. The innovative nature of the UAV modernization project, which involves implementing new control and coordination functions within a drone swarm using artificial intelligence [10, 11].
2. The diversity of components integrated into UAVs for executing advanced control functions, which increases the complexity of the system architecture [12, 13].
3. Operational constraints affecting UAV performance, including size, combat payload, and flight endurance [14, 15].
4. The necessity of finding a compromise between developing new innovative UAV components and utilizing existing ones, which impacts the success of the modernization project [16, 17].
5. The presence of time and budget constraints for executing the UAV modernization project under the conditions of a national emergency [18, 19].
6. The complexity of assembling a team of specialists for the successful implementation of the UAV modernization project [20, 21].
7. Challenges associated with employing modern technological equipment for mass production of new UAVs or the modernization of existing ones [22, 23].
8. Supply chain issues related to sourcing components for UAV production under the conditions of a national emergency [24, 25].

This is not an exhaustive list of challenges, as new issues continue to emerge under the country's current state of emergency. This highlights the relevance and necessity of implementing UAV modernization projects to enable the execution of new combat missions using drone swarms.

A review of publications addressing these challenges has demonstrated the complexity of UAV modernization tasks under existing national conditions. This necessitates further research employing various models for analyzing and planning project activities [26].

This study proposes a possible solution to a subset of these issues, specifically:

− Justification for developing a modern component-based UAV architecture to support new flight coordination and control functions within drone swarms.

− Selection of the optimal modernization option from a set of existing UAV configurations.

− Development of optimization models to ensure the efficiency of the UAV modernization project.

− Implementation of simulation modeling of project activities over time to evaluate the key performance indicators of the UAV modernization project.

The study applies a systems analysis approach to UAV modernization, incorporating both structural and dynamic aspects of the research.

Structural analysis is conducted to develop the UAV architecture using a component-based approach [27]. This involves evaluating a set of components, including both existing and newly developed elements, which will be integrated into the modernized UAV model. The search for the optimal modernization option is performed through lexicographic ordering of alternatives, ensuring a rational selection process. Additionally, optimization of key performance indicators in the modernization project is achieved using integer (Boolean) programming.

These well-established methods have been successfully applied across various domains where multiple alternative solutions exist, and the most suitable option must be selected.

For dynamic analysis, an advanced simulation modeling of project activities is employed, utilizing an agent-based approach. This technique enables interactive control of the simulation within a chosen time scale, allowing for the detailed investigation of the logical sequence of project activities involved in UAV modernization.

### 1.3. Objectives and methodology

A critical contradiction arises between the urgent need to modernize UAVs within short timeframes – enabling new innovative functions for swarm flight control and coordination – and the limitations of existing models, as well as the lack of new frameworks that fully support project planning for UAVs with advanced components under the country's special operational conditions.

The objective of this research is to develop a comprehensive set of mathematical and simulation models that facilitate UAV modernization planning. These models aim to support the implementation of new control, coordination, and navigation functions for deployment in military drone swarm missions.

In accordance with this objective, the following key tasks must be addressed:

1. Conduct a system analysis of UAV modernization processes for application in modern military operations.
2. Evaluate a set of alternative UAV configurations to identify the most suitable option for modernization.
3. Optimize key performance indicators of the UAV modernization project, considering the component-based architecture of the system.
4. Develop a simulation model to analyze, over time, the sequence of project activities related to UAV modernization.

The article structure is as follows:

- Section 2 is dedicated to the system analysis of possible modernization strategies for UAVs.
- Section 3 focuses on the development of a model for selecting the most rational UAV modernization option among existing alternatives, using lexicographic ordering of alternatives.
- Section 4 addresses the optimization of the UAV component architecture to ensure compliance with the key performance indicators defined in the modernization project.
- Section 5 presents the simulation modeling of project activities related to UAV modernization.
- Section 6 discusses the scientific results and presents them as a methodology, emphasizing the practical significance of the conducted research.
- Section 7 concludes the article by summarizing the findings, outlining prospects for future research, and exploring the development of an applied information technology for UAV modernization.

## 2. System Analysis of the UAV Modernization Process for Deployment in Modern Military Missions

The extensive deployment of unmanned aerial systems in the Land Forces and the State Border Guard Service enables the formation of a Kill Zone, restricting enemy movement without incurring losses. The integration of aerial operations using UAVs with ground-based military actions significantly reduces personnel casualties and facilitates the elimination of enemy targets before they reach the frontline. Establishing such an integrated strike system will dramatically enhance the effectiveness of both defensive and offensive operations. Consequently, UAVs have become a key element of modern warfare, directly contributing to battlefield success.

However, current UAVs – such as reconnaissance drones, target designators, and strike drones – lack the necessary functionality to conduct large-scale swarm attacks. This limitation stems from the absence of essential structural features required for the management and coordination of UAV swarms. As a result, the need arises for developing new UAVs or modernizing existing ones to achieve these capabilities.

Developing entirely new UAVs involves high costs, long development cycles, and increased project risks, making this approach impractical under the constraints of a national emergency. An alternative solution involves the modernization of existing UAVs, which have already demonstrated their battlefield effectiveness, are produced serially, and are available in sufficient quantities within the armed forces. The modernization of such UAVs focuses on structural enhancements,

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

which can be efficiently implemented by leveraging the component-based architecture of modern UAVs.

When modernizing UAVs, several key factors must be considered:

1. The emergence of numerous new UAV control functionalities, including swarm formation, group-based task execution, and flock-based flight coordination.

2. Adaptation of existing UAV components to meet the technical requirements of the modernization project.

3. Full-cycle development of new components required for the modernization process.

4. Time constraints, necessitating an accelerated modernization process due to the urgency of the national security situation.

5. Risk factors associated with project execution, especially under emergency conditions.

The listed factors must be considered when planning projects for the modernization of existing UAVs.

A set of possible modernization strategies has been formulated, taking into account the specific state of the country:

1. Modernization strategy based on the reengineering of all UAV components.

This approach enables the implementation of new functionalities by modernizing almost all UAV components.

2. Modernization strategy based on identifying components that do not require upgrades and can be used in their current form.

In this case, designers focus on components that, after reengineering, can perform new flight control and coordination functions.

3. Modernization strategy based on designing new components that are absent in the UAV without altering the existing ones.

This strategy allows for the separation of newly developed components, concentrating efforts on their creation.

4. Component-based UAV design strategy.

Here, the UAV architecture is formed by representing functional elements as relatively isolated components. These components can be assembled into the required architecture depending on the UAV's objectives and mission requirements in military operations.

The presented list of UAV modernization strategies is not exhaustive and may be expanded with new strategies that emerge under special conditions in the country.

The methods and models developed in this study can be applied not only to UAV modernization projects but also to the upgrading of existing military equipment and weapon systems. The reengineering of modern military technology using a component-based approach will ensure effective deployment in the context of contemporary hybrid warfare.

Thus, this section provides a system analysis of the UAV modernization process. The study identifies key factors influencing modernization projects and presents possible strategies. Further research in this publication will focus on employing a modern component-based approach to UAV modernization, particularly for their deployment in military missions as drone swarms.

## 3. Analysis of Alternative UAV Options for Selecting the Most Suitable Model for Modernization

Existing UAV models used by the military comprise a set of possible alternatives, from which the most suitable option for the modernization project must be selected. The selection of the optimal modernization option from this set is associated with the evaluation of key performance indicators that reflect the objectives and tasks of the UAV modernization project.

The formation of performance indicators depends on customer requirements and the specific missions the UAVs will perform, such as reconnaissance, target designation, or strike operations. Consider an illustrative example of UAV modernization for use in offensive missions. To carry out attacks against enemy targets using a drone swarm, the following capabilities of the drones must be considered:

- the drone swarm formation – P;
- targeted flight within the swarm – Q;
- drone groups formation within the swarm – V;
- combat potential – F;
- size of the impact zone – Z;
- flight time to the target – T.

At the initial stages of the UAV modernization project, the selection of the most suitable unmanned aerial vehicle for enhancement will be based on qualitative assessments provided by experts (including UAV developers, military personnel, etc.). These assessments will be represented in the form of values of the linguistic variable $y_{ij}$ [4]:

$$y_{ij} = \begin{cases} \text{A – very high grade,} \\ \text{B – high grade,} \\ \text{C – good grade,} \\ \text{D – satisfactory grade,} \\ \text{E – low grade.} \end{cases} \quad (1)$$

where "i" refers to the i-th indicator (P, Q, V, F, Z, T), and "j" refers to the j-th possible UAV option subject to modernization.

For example, for indicator F:

$$y_{ij} = \begin{cases} \text{A – very high combat potential,} \\ \text{B – high combat potential,} \\ \text{C – good combat potential,} \\ \text{D – satisfactory combat potential,} \\ \text{E – low combat potential.} \end{cases} \quad (2)$$

Next, it is necessary to assess the significance of individual performance indicators by establishing a prioritized ranking based on expert opinions. Suppose the experts have formulated the following priority order of indicators:

P, Q, F, Z, T, V (3)

For example, the set of alternative options for participation in the UAV modernization project consists of ten alternatives. A qualitative assessment of the indicators for each option will be conducted, considering the values of the linguistic variable $y_{ij}$ and using the established ranking of indicators (P, Q, F, Z, T, V):

1. B, C, C, A, B, B
2. B, A, B, B, C, B
3. A, C, C, B, E, C
4. D, D, A, B, B, C (4)
5. C, B, B, C, D, E
6. A, B, D, C, E, B
7. B, C, B, D, C, B
8. B, A, C, C, D, E
9. B, B, C, B, A, C
10. A, B, D, D, C, E.

Let us assume that experts have excluded alternatives with very low performance ratings (E) (specifically, alternatives 3, 5, 6, 8, and 10). This results in a reduced set of alternatives:

1. B, C, C, A, B, B
2. B, A, B, B, C, B
4. D, D, A, B, B, C (5)
7. B, C, B, D, C, B
9. B, B, C, B, A, C.

To prioritize these alternatives, we apply lexicographic ordering, taking into account the qualitative values of the linguistic variable $y_{ij}$ and the established priority sequence of performance indicators (P, Q, F, Z, T, V). Using lexicographic sorting (similar to dictionary ordering), we obtain the following ranked list:

2. B, A, B, B, C, B
9. B, B, C, B, A, C
7. B, C, B, D, C, B (6)
1. B, C, C, A, B, B
4. D, D, A, B, B, C.

The most suitable alternatives for UAV modernization are positioned at the top of the list. The best option, based on the lexicographic ordering, is the second alternative**,** which is characterized by the following performance indicators:

− high potential for deployment within a swarm of drones;
− very high capability for coordinated flight within the swarm;
− high combat potential of the UAV;
− good rating for target area coverage;
− good flight time to target;
− satisfactory capability for forming a swarm group.

Thus, this section presents an analysis of a set of existing UAV alternatives that can be considered for the selection of the most suitable option for the modernization project. The evaluation criteria focus on UAV capabilities relevant to swarm-based attack operations. To simplify the assessment process, expert evaluations are expressed using qualitative ratings in the form of linguistic variables. The final selection of the most appropriate UAV modernization option is carried out using lexicographic ordering of alternatives, ensuring that the most critical performance indicators are prioritized.

## 4. Optimization of Key Performance Indicators in UAV Modernization Considering Component-Based Architecture

The emergence of new UAV capabilities in swarm flight is closely linked to the further enhancement of military missions in modern warfare, which heavily relies on drone deployment. The need to form drone swarms for wave attacks necessitates the development of new components and their integration into the existing UAV architecture. Adopting a component-based design approach simplifies the UAV modernization process, enabling further improvement.

Under a modern component-based approach, the architecture of a complex system consists of the following component types:

− legacy components from previous developments;
− components requiring adaptation (modernization) to meet the technical requirements of the modernization project;
− new (innovative) components, designed to introduce functionalities absent in existing UAV models.

It is essential to note that new components significantly impact the key performance indicators of the modernization project. The project timeline and cost increase, and, more importantly, risks emerge in the

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

development of new components, affecting the modernization project feasibility. This creates a challenging trade-off between integrating new components into the UAV architecture and mitigating the risks associated with their development.

To address this issue, we propose a formalized approach to identifying a rational UAV modernization option, considering possible component configurations. For this purpose, integer (Boolean) programming will be employed [28]. We introduce a Boolean variable $x_{ij}$, where index i corresponds to a new component intended to introduce a new UAV function (e.g., UAV swarm formation), and index j – represents the developer's decision regarding the creation (or modernization) of the component:

$$x_{ij} = \begin{cases} 1, \text{ if the implementation of a new i-th UAV function requires the creation of a new component through the involvement of j-th developer in the modernization project;} \\ 0, \text{ if the implementation of a new i-th UAV function requires adapting an existing component while involving j-th developer.} \end{cases} \quad (7)$$

For planning a UAV modernization project, the following indicators must be considered:

- time required for project implementation – T;
- project execution risks – R;
- cost of project works related to modernization – W.

The indicators T, R, and W can be represented using the Boolean variable $x_{ij}$:

$$T = \sum_{i=1}^{N}\sum_{j=1}^{n_i} t'_{ij}\, x_{ij} + \sum_{i=1}^{N}\sum_{j=1}^{n_i} t''_{ij}(1 - x_{ij}), \quad (8)$$

where $t_{ij}$' – the time required to develop a new i- th component by the j- th developer;

$t_{ij}$'' – the time required to modernize (adapt) the i-th component by the j-th developer;

if $x_{ij}$ =1, then 1-$x_{ij}$=0 and the first summation term is used, which corresponds to the development of a new component;

if $x_{ij}$ =0, then 1-$x_{ij}$=1 and the existing component is modernized using the second summation term;

$n_i$ – the number of possible developers for either creating or modernizing the i-th component;

N – the total number of components that need to be developed or modernized.

Thus, the value T accounts for both the creation of new components and the modernization of existing ones.

Notably, the representation of time (T) is highly simplified and corresponds to the sequence of project activities related to the development (or modernization) of components. In actual design practice, the process of developing (or modernizing) components may occur in parallel or in a sequential-parallel manner. However, at the initial stage of design, the time required for the design process of new components (or the modernization of existing ones) can be approximately estimated using equation (8).

The risks associated with the modernization project:

$$R = \sum_{i=1}^{N}\sum_{j=1}^{n_i} r'_{ij}\, x_{ij} + \sum_{i=1}^{N}\sum_{j=1}^{n_i} r''_{ij}(1 - x_{ij}), \quad (9)$$

where $r'_{ij}$ – represents the risk of project activities related to the development of a new component;

$r''_{ij}$ – represents the risk of activities associated with the modernization of existing components.

The cost of project activities:

$$W = \sum_{i=1}^{N}\sum_{j=1}^{n_i} w'_{ij}\, x_{ij} + \sum_{i=1}^{N}\sum_{j=1}^{n_i} w''_{ij}(1 - x_{ij}), \quad (10)$$

where $w'_{ij}$ – pertains to the development of a new component;

$w''_{ij}$ – pertains to the modernization of an existing component.

To solve the optimization problem related to the development of new components (or the modernization of existing ones), one of the indicators T, R, W can be used as the objective function while imposing constraints on the others.

For example, if the goal is to minimize project risks during the UAV modernization process:

$$\min R,\ R = \sum_{i=1}^{N}\sum_{j=1}^{n_i} r'_{ij}\, x_{ij} + \sum_{i=1}^{N}\sum_{j=1}^{n_i} r''_{ij}(1 - x_{ij}), \quad (11)$$

subject to the constraints:

$$T \le T',\ T = \sum_{i=1}^{N}\sum_{j=1}^{n_i} t'_{ij}\, x_{ij} + \sum_{i=1}^{N}\sum_{j=1}^{n_i} t''_{ij}(1 - x_{ij}), \ldots (12)$$

$$W \le W',\ W = \sum_{i=1}^{N}\sum_{j=1}^{n_i} w'_{ij}\, x_{ij} + \sum_{i=1}^{N}\sum_{j=1}^{n_i} w''_{ij}(1 - x_{ij}), \quad (13)$$

where T’, W’ – represent the acceptable values for the time and cost of implementing UAV component modernization.

To determine a compromise among the indicators T, R, W, it is necessary to assess the importance of individual indicators with the assistance of experts (specialists in reengineering). These experts assign weights to the indicators:

$$\alpha_T + \alpha_R + \alpha_W = 1 \tag{14}$$

To find an optimal balance, a comprehensive indicator should be used:

$$Q = \alpha_T T + \alpha_R R + \alpha_W W, \tag{15}$$

where $T, R, W$ – are the normalized values of the indicators.

$$T = \frac{T - T^*}{T' - T^*},\quad R = \frac{R - R^*}{R' - R^*},\quad W = \frac{W - W^*}{W' - W^*}, \tag{16}$$

where T*, R*, W* – the minimal values of the indicators obtained after optimization for individual criteria.

The comprehensive indicator must be minimized:

$$\min Q,\ Q = \alpha_T T + \alpha_R R + \alpha_W W. \tag{17}$$

The method for solving an integer (Boolean) programming problem depends on the dimensionality of the task [29]:

− for small-scale problems, complete enumeration can be used;

− for large-scale problems, an improved branch-and-bound method is applicable;

− for very high-dimensional problems, a random search method is necessary. Although it does not guarantee finding the extremum, it can provide improvements in the key performance indicators relative to the original representations (for example, in percentage terms).

Thus, in this section, the task of optimizing the project indicators related to the modernization of UAVs was addressed using a component-based representation of the architecture of the new product. The approach distinguishes between components that need to be newly created and those that require modernization. The primary project indicators include time, cost, and project risks. For the optimization process, the integer (Boolean) programming method was employed. In order to search for a compromise among the presented performance indicators, multi-criteria optimization was employed.

## 5. Simulation Model for Time-Based Research of UAV Modernization Project Activities

The set of project activities for the modernization of UAVs, aimed at adapting them for contemporary military missions, depends on the characteristics of the UAV system's component architecture. The ratio between reusable components with demonstrated operational demand and newly integrated components required for executing modern combat functions influences the time, cost, and risks associated with the modernization project. The implementation of UAV modernization project activities is closely tied to the life cycle of developing a complex high-tech system.

Let us consider the following key stages of the UAV modernization project.

1. Development of new components or modernization of existing ones. This stage includes: Research and development (R&D), Experimental design work (EDW), Testing of prototype components (TPC), Production preparation (PP), Serial production of new components (SPC).

2. Integration of new components into the existing UAV architecture (IC).

3. Creation of UAV prototypes with the updated architecture (CUP).

4. Testing of the modernized UAV system (TMS).

5. Production preparation (technical and technological) (PP).

6. Serial production of the modernized UAV (SP).

The above-listed project activities can be carried out sequentially or in a mixed sequential-parallel manner, making analytical modeling approaches challenging. Therefore, simulation modeling was employed to represent project activities within a given time frame. The AnyLogic agent-based simulation platform was used for this purpose. The developed simulation model includes a set of agents reflecting the UAV modernization life cycle:

1. Component architecture formation agent (CAF) for the UAV complex.

2. R&D modeling agent for new (or modernized) components.

3. EDW modeling agent for new (or modernized) components.

4. TPC modeling agent for new (or modernized) components.

5. CPP modeling agent for component production preparation.

6. SPC modeling agent for the serial production of new (or modernized) components.

7. IC modeling agent for the integration of components into the new UAV architecture.

8. CUP agent for the development of UAV prototypes.

9. TMS agent for testing the modernized UAV.

10. PP agent for UAV production preparation.

11. SP agent for the serial production of the modernized UAV.

12. Project timeline initialization (PTI) agent (2-11).

13. "Interactive Management" agent.

14. "Simulation Results" agent.

15. "Threat" agent. This agent simulates potential threats (e.g., military threats) that may lead to project delays, affecting the overall UAV modernization timeline.

The structure of the agent-based model is illustrated in Figure 1.

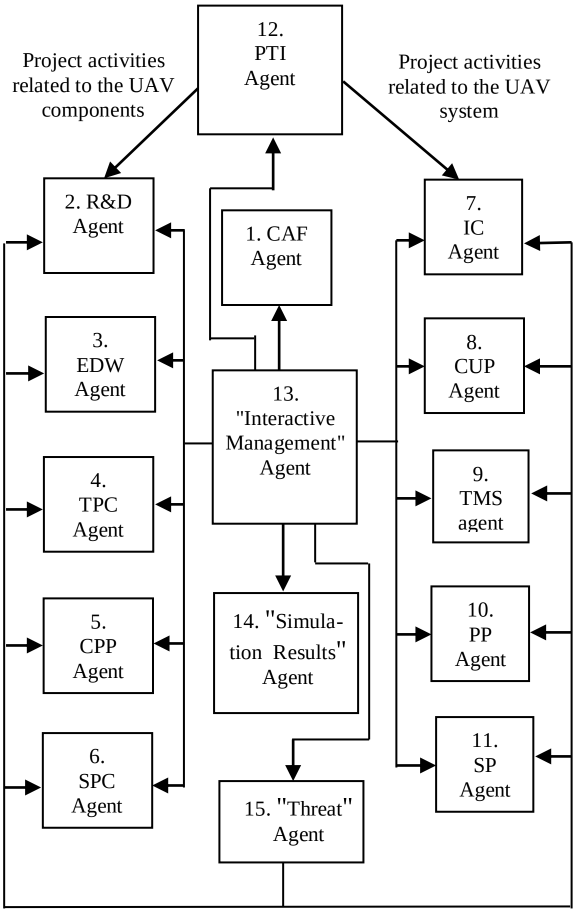


Fig. 1. Structure of the agent based simulation model

As a result of modeling the project activities related to the modernization of UAVs for their use in modern military missions, the following output data were obtained:

− the duration of the UAV modernization project;

− the timelines for individual project activities (2–11);

− the duration of project activities related to the development of new components (or the modernization of existing ones);

− the start time for integrating components into the UAV architecture;

− the initiation timeline for serial production of the modernized UAV;

− the ratio of actual to planned project completion timelines for UAV modernization (expressed as a percentage);

− the increase in project duration due to the impact of threats (both in absolute time and percentage terms).

Thus, this section presents the modeling of key project activities, including the development of individual components (or the modernization of existing ones), as well as activities associated with component integration into a new UAV architecture, production preparation, and serial manufacturing of modernized UAVs. To analyze the sequence of project activities within a given time scale, a simulation modeling method was employed by developing a multi-agent model on the AnyLogic platform. The model accounts for potential threat-related actions that may impact the overall timeline of the UAV modernization project.

## 6. Discussion

A systemic representation of the UAV modernization process has been developed to enhance its application in modern military missions. This is achieved by implementing new functionalities in control, coordination, and flight navigation to enable drone swarm formation and large-scale wave attacks on enemy targets. Various strategies for upgrading high-tech systems have been analyzed.

A modern component-based approach has been applied to UAV architecture development, distinguishing between reusable components and those that need to be newly developed or upgraded. The efficiency of the UAV modernization process using this approach has been evaluated. A set of potential UAV configurations has been identified and analyzed for modernization, considering the technical requirements of the project.

At the initial project stage, expert qualitative assessments and lexicographic ordering of alternative options are employed to select the most suitable existing UAV for modernization. Optimization of time, cost, and risk indicators for selecting UAV components – either newly developed or upgraded – has been conducted using integer (Boolean) programming. Additionally, a time-sequenced simulation of project activities has been carried out to evaluate the temporal characteristics of the UAV modernization project using a developed multi-agent simulation model.

The following research methodology is proposed:

1. Systemic analysis of the UAV modernization process to ensure effective deployment in hybrid warfare military missions.
2. Application of a modern component-based approach to UAV modernization.
3. Selection of the most suitable existing UAV for integration into the modernization project.
4. Optimization of time, cost, and risk factors in the UAV modernization project.
5. Time-sequenced modeling of sequential-parallel project activities for UAV modernization.

The necessity of modernizing existing UAVs for effective use in contemporary warfare underscores the relevance of this approach.

A comprehensive set of models has been developed to facilitate the planning of UAV modernization projects, focusing on the further integration of air and ground combat operations. This confirms the timeliness and effectiveness of the proposed approach in strengthening national defense capabilities by leveraging innovative military technologies, particularly UAV swarms.

Future research will focus on refining applied information technology for UAV modernization modeling, utilizing the component-based approach to ensure the successful execution of modernization projects.

## 7. Conclusions

The conducted research enables the planning of measures and actions for the modernization of existing UAV for use in contemporary military missions, specifically:

− selecting an appropriate modernization strategy under the conditions of a special state in the country;

− justifying the selection of an existing UAV for its integration into the modernization project;

− optimizing the time, costs, and risks associated with the modernization project, considering the necessity of developing new or upgrading existing UAV components;

− analyzing the execution of the UAV modernization project through the application of simulation modeling of project activities.

The scientific novelty of the research lies in the development of original and innovative models that facilitate: the analysis of existing UAVs for their further modernization, the justification of selecting new components within the component-based architecture of the system, the assessment of time and risks associated with the implementation of the UAV modernization project under special state conditions through the simulation modeling of project activity sequences.

Thus, the main contribution of this research is as follows: the proposed set of models provides a scientifically grounded approach to UAV modernization projects, ensuring their applicability in modern military missions. It enables the selection of an optimal modernization strategy while accounting for time, costs, and risks in conditions of a special state.

This, in turn, enhances the effectiveness of UAV deployment in military operations and facilitates the further integration of ground and aerial combat actions, ultimately contributing to the strengthening of national defense capabilities.

**Contribution of authors**: system analysis of the UAV modernization process – **Oleg Fedorovych**; development of models for optimizing project activities – **Leonid Malieiev**; simulation modeling of the modernization project – **Oleksii Hubka**; agent-based modeling of logistics actions for UAV modernization – **Andrei Popov**.

### 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.

### Financing

This research was conducted without financial support.

### Data availability

The manuscript has no associated data.

### Use of Artificial Intelligence

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

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

## References

1. Zhang, J., Campbell, J., Sweeney, D., & Hupman, A. Energy consumption models for delivery drones: A comparison and assessment. *Transportation Research Part D: Transport and Environment,* 2023, vol. 90, article no. 102668. DOI: 10.1016/j.trd.2020.102668.
2. Abdelkader, M., Güler, S., Jaleel, H., & Shamma, J. S. Aerial swarms: Recent applications and challenges. *Current robotics reports,* 2021, no. 2, pp. 309-320. DOI: 10.1007/s43154-021-00063-4.

3. Asaamoning, G., Mendes, P., Rosário, D., & Cerqueira, E. Drone swarms as networked control systems by integration of networking and computing. *Sensors*, 2021, no. 21 (8), article no. 2642. DOI:10.3390/s21082642.

4. Fedorovych, O., Kritskiy, D., Malieiev, L., Rybka, K., & Rybka, A. Military logistics planning models for enemy targets attack by a swarm of combat drones. *Radioelectronic and Computer Systems*, 2024, no. 1, pp. 207-216. DOI: 10.32620/reks.2024.1.16.

5. Qian, F., Su, K., Liang, X., & Zhang, K. Task Assignment for UAV Swarm Saturation Attack: A Deep Reinforcement Learning Approach. *Electronics*, 2023, vol. 12, iss. 6, article no. 1292. DOI: 10.3390/electronics12061292.

6. Matrunchyk, D. M. Modernization of the Military-Industrial and Security Complex as the Main Link in the Innovative Transformation of the Post-War Economy of the Regions of Ukraine. *Problemy Ekonomiky*, 2023, no. 3, pp. 81-87. DOI: 10.32983/2222-0712-2023-3-81-87.

7. Mosov, S. Swarming of military drones: realities and prospects. *Collection of scientific papers of the Centre for Military and Strategic Studies of the National Defence University of Ukraine*, 2024, no. 1 (80), pp. 77-86. DOI: 10.33099/2304-2745/2024-1-80/77-86.

8. Fedorovich, O., Uruskiy, O., Pronchakov, Y., & Lukhanin, M. Method and information technology to research the component architecture of products to justify investments of high-tech enterprise. *Radioelectronic and Computer Systems*, 2021, no. 1, pp. 150-157. DOI: 10.32620/reks.2021.1.13.

9. Kushnir, O. I., Davykoza, O. P., & Kucherenko, Y. F. Analysis of the impact of hybrid warfare on the development of an automated aviation and air defense control system of the Air Force of Ukraine. *Science and Technology of the Air Force of Ukraine*, 2017, no. 2, pp. 116-120. Available at: http://nbuv.gov.ua/UJRN/Nitps_2017_2_25.

10. Puente-Castro, A., Rivero, D., Pazos, A., & Fernandez-Blanco, E. A review of artificial intelligence applied to path planning in UAV swarms. *Neural Computing and Applications*, 2022, no. 34, pp. 153–170. DOI: 10.1007/s00521-021-06569-4.

11. Caballero-Martin, D., Lopez-Guede, J. M., Estevez, J., & Graña, M. Artificial intelligence applied to drone control: A state of the art. *Drones*, 2024, no. 8, iss. 7, article no. 296. DOI: 10.3390/drones8070296.

12. Sanchez-Lopez, J.L., Pestana, J., de la Puente, P., & Campoy P. A Reliable Open-Source System Architecture for the Fast Designing and Prototyping of Autonomous Multi-UAV Systems: Simulation and Experimentation. *Journal of Intelligent & Robotic Systems*, 2016, no. 84, pp. 779–797. DOI: 10.1007/s10846-015-0288-x.

13. Gromada, K. A., & Stecz, W. M. Designing a Reliable UAV Architecture Operating in a Real Environment. *Applied Sciences*, 2022, no. 12, iss. 1, article no. 294. DOI: 10.3390/app12010294.

14. Movchan, K. O. Classification systems for unmanned aerial vehicles and their application in various industries. *Scientific notes of Taurida National V.I. Vernadsky University. Series: Technical Science*, 2024, vol. 35 (74), no. 6, part 1, pp. 1-7. DOI: 10.32782/2663-5941/2024.6.1/01.

15. Fan, B., Li, Y., Zhang, R., & Fu, Q. Review on the technological development and application of UAV systems. *Chinese Journal of Electronics,* 2020, no. 29, 2, pp. 199-207. DOI: 10.1049/cje.2019.12.006.

16. Fedorovich, O., Lutai, L., Kompanets, V., & Bahaiev, I. The Creation of an Optimisation Component-Oriented Model for the Formation of the Architecture of Science-Based Products. In: *Integrated Computer Technologies in Mechanical Engineering - 2023. ICTM 2023. Lecture Notes in Networks and Systems*, 2024, vol. 996, pp. 415-426, Springer, Cham. DOI: 10.1007/978-3-031-60549-9_31.

17. Fedorovich, O., Lutai, L., Trishch, R., Zabolotnyi, O., Khomiak, E., & Nikitin, A. Models for Reducing the Duration and Cost of the Aviation Equipment Diagnostics Process Using the Decomposition of the Component Architecture of a Complex Product. In: *Information Technology for Education, Science, and Technics. ITEST 2024. Lecture Notes on Data Engineering and Communications Technologies*, 2024, vol. 221, pp. 108-125, Springer, Cham. DOI: 10.1007/978-3-031-71801-4_9.

18. Demidov, B. O., Velichko, O. F., Kucherenko, Y. F., & Kutsak, M. V. Project management for the creation of weapons and military equipment samples in conditions of uncertainty and risk factors. *Armaments and military equipment*, 2016, no. 2, pp. 14-18. Available at: http://nbuv.gov.ua/UJRN/ovt_2016_2_4. (accessed 1.12.2024).

19. Chepkov, I. B., Lukhanin, M. I., & Borokhvostov, I. V. *Armaments and military equipment*, 2016, no. 4, pp. 3-8. Available at: http://nbuv.gov.ua/UJRN/ovt_2016_4_2. (accessed 11.12.2024).

20. Idries, A., Mohamed, N., Jawhar, I., Mohamed F., & Al-Jaroodi, J. Challenges of developing UAV applications: A project management view. *Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management (IEOM)*, Dubai, United Arab Emirates, 2015, pp. 1-10. DOI: 10.1109/IEOM.2015.7093730.

21. Nechyporuk, M., Fedorovich, O., Popov, V., & Romanov M. Modeling of specialists' profiles for planning and implementation of projects for the creation of innovative products of aerospace tech-

niques. *Radioelectronic and Computer Systems*, 2022, no. 1, pp. 23-35. DOI: 10.32620/reks.2022.1.02.

22. Samusenko, D., & Sych, M. Innovations in 3D printing technology and their application to create UAVs with minimization of defects using lightweight plastic. *Collection of Scientific Papers «ΛΌГОΣ»,* (February 14, 2025; Boston, USA), pp. 167–171. DOI: 10.36074/logos-14.02.2025.035.

23. Fan, B., Li, Y., Zhang, R., & Fu, Q. Review on the technological development and application of UAV systems. *Chinese Journal of Electronics*, 2020, no. 29, iss. 2, pp. 199-207. DOI: 10.1049/cje.2019.12.006.

24. Fedorovich, O., Pronchakov, Y., Leshchenko, Y., & Yelizieva, A. Using of the component method in logistics of supplies of high-tech production components. *Advanced Information Systems*, 2021, no. 5, iss. 3, pp. 40–45. DOI: 10.20998/2522-9052.2021.3.06.

25. Hashemi, S. R., Arasteh, A. & Paydar, M. M. Risk Management of Disruption and Sustainable Development of Supply Chains. *Interdisciplinary Journal of Management Studies (Formerly known as Iranian Journal of Management Studies),* 2023, no. 16, iss. 1, pp. 277-297. DOI: 10.22059/ijms.2022.329830.674732.

26. Antonova, A., Aksyonov, K., & Ziomkovskaya, P. Development of a Method and a Software for Decision-Making, System Modeling and Planning of Business Processes. In: *Frontiers in Software Engineering. ICFSE 2021. Communications in Computer and Information Science*, 2021, vol. 1523, pp. 148-157. Springer, Cham. DOI: 10.1007/978-3-030-93135-3_10.

27. Fedorovich, O., Pronchakov, Y., Yelizieva, A. & Leshchenko, Y. Simulation of the business processes of the developing enterprise to create complex products with multi-level component architecture. *Aerospace Technic and Technology*, 2021, no. 4, pp. 79-86. DOI: 10.32620/aktt.2021.4.11.

28. Pavlov, A., & Kyselov, M. Математичні моделі та методи узгодженого планування. *Bulletin of National Technical University "KhPI". Series: System Analysis, Control and Information Technologies*, 2023, no. 2 (10), pp. 3-8. DOI: 10.20998/2079-0023.2023.02.01.

29. Rybalchenko, A. An improved method of cutting off non-promising options for the problem of integer linear programming with Boolean variables based on the rank approach. *Scientific Works of Kharkiv National Air Force University*, 2023, no. 3 (77), pp. 62-66. DOI: 10.30748/zhups.2023.77.09.

*Надійшла до редакції 05.02.2025, розглянута на редколегії 17.03.2025*

## МОДЕЛЮВАННЯ ПРОЄКТНИХ ДІЙ ЩОДО МОДЕРНІЗАЦІЇ БПЛА ДЛЯ ПРОВЕДЕННЯ АТАКУЮЧИХ МІСІЙ РОЄМ ДРОНІВ

***О. Є. Федорович, Л. В. Малєєв, О. С. Губка, А. В. Попов***

Формується та вирішується актуальна задача дослідження модернізації існуючих БПЛА для їх використання в сучасних умовах гібридної війни. Дослідження, яке проводиться, спрямоване на адаптацію існуючої структури БПЛА, шляхом реінжинірингу, для забезпечення можливостей проведення бойових дій в формі ройових атак за актуальними цілями противника. Тому, актуальна тема запропонованої публікації, в якій досліджуються необхідні заходи щодо планування проєктних дій, пов’язаних з модернізацією існуючих БПЛА та їх наближення до потреб військових на полі бою. Метою публікації є створення комплексу математичних та імітаційної моделей, за допомогою яких можна планувати проєкт модернізації БПЛА за напрямком виконання нових функцій управління, координації та навігації, для використання у військових місіях рою дронів. Проаналізовані існуючі проблеми реінжинірингу високотехнологічних виробів для використання в умовах застосування, які змінюються. Представлені можливі стратегії реінжинірингу БПЛА. Особлива увага приділяється компонентному підходу для створення нових, або модернізації існуючих БПЛА. Відокремлюються можливі типи компонент, які входять до архітектури сучасного високотехнологічного виробу (існуючі компоненти, компоненти, які необхідно модернізувати, нові компоненти). Зроблено висновок про необхідність пошуку компромісу між існуючими компонентами, які повторно використовуються, та новими (інноваційними) компонентами. Інноваційні компоненти призводять до збільшення часу, витрат та ризиків проєкту модернізації, що необхідно враховувати в період воєнного стану країни. Аналізуються існуючі БПЛА для використання в проєктах модернізації. На початкових етапах проєкту модернізації БПЛА, для вибору найкращого варіанту серед можливих, використовуються якісні оцінки експертів (фахівців виробництва складних виробів, військових) у формі якісних значень лінгвістичної змінної. За допомогою лексикографічного впорядковування варіантів формується раціональний варіант для участі в проєкті модернізації. Втілення нових компонент в існуючу архітектуру БПЛА потребує пошуку оптимальних рішень щодо реінжинірингу в умовах скорочення часу, витрат та ризиків особливого стану країни. Створюється оптимізаційна модель для вибору раціональної компонентної архітектури БПЛА з використанням цілочисельного (булевого) програмування. Велика увага приділяється дослідженню послідовності проєктних дій щодо модернізації БПЛА, для оцінки часу виконання проєкту та ризиків його реалізації. Створена імітаційна модель для

*ISSN 1814-4225 (print)*
*ISSN 2663-2012 (online)*

аналізу, у заданому масштабі часу, життєвого циклу створення нових (або модернізації існуючих) компонент, а також проєкту модернізації у цілому. За допомогою агентної платформи Any Logic проводиться інтерактивне моделювання проєктних дій щодо модернізації БПЛА. Наукова новизна дослідження пов’язана зі створенням оригінальних та нових моделей, які дозволять проаналізувати існуючі БПЛА для їх подальшої модернізації, обґрунтувати вибір нових компонент в архітектурі виробу, провести оцінку часу, ризиків реалізації проєкту модернізації БПЛА в умовах особливого стану країни, шляхом імітаційного моделювання послідовності проєктних дій. Результати дослідження доцільно використовувати при плануванні процесу модернізації існуючих БПЛА для наближення їх можливостей до вимог сучасної гібридної війни, де потрібно інтегрувати дії в повітрі з діями військових на полі бою, що забезпечить підвищення обороноздатності країни.

**Ключові слова:** модернізація БПЛА; можливі стратегії модернізації; пошук найкращого варіанту модернізації; оптимізація основних показників; лексикографічне впорядковування варіантів; імітаційне моделювання проєктних дій; багатокритеріальна оптимізація.

**Федорович Олег Євгенович** – д-р техн. наук, проф., зав. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

**Малєєв Леонід Вікторович** – аспірант. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

**Губка Олексій Сергійович** – канд. техн. наук, доц., доц. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

**Попов Андрій Вячеславович –** канд. техн. наук, доц., доц. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

**Oleg Fedorovych** – Doctor of Technical Sciences, Professor, Head of the Computer Science and Information Technologies Department, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: o.fedorovych@khai.edu, ORCID: 0000-0001-7883-1144.

**Leonid Malieiev** – Ph.D. Student of the Department of Computer Science and Information Technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: leonid.maleev@gmail.com, ORCID: 0009-0008-8896-2138.

**Oleksii Hubka** – Candidate of Technical Sciences, Associate Professor, Associate Professor at the Department of Computer Science and Information Technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: o.gubka@khai.edu, ORCID: 0009-0009-7954-5639.

**Andrei Popov** – Candidate of Technical Science, Associate Professor, Associate Professor at the Computer Science and Information Technologies Department, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine,
e-mail: a.popov@khai.edu; ORCID: 0000-0001-8984-731X.