

Oleg FEDOROVICH, Andriy POPOV, Tetyana PISKLOVA,
Leonid MALIEIEV, Andriy RYBKA, Valeriy FEDOROVICH

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

MODELING THE LIFE CYCLE REDUCTION FOR THE RAPID DEVELOPMENT OF UAVs FOR USE IN MILITARY MISSIONS

*Modern warfare has changed the understanding of strategy, tactics, and the use of new types of equipment, both in terms of operational-tactical actions and new technologies in military systems. The emergence of UAVs of various types has enabled their use not only on the battlefield but also deep behind enemy lines. However, to achieve parity with the adversary in military operations, it is necessary to ensure the rapid implementation of innovations in the development of new military equipment, with the ability to scale and mass-produce the required volume of weaponry. Therefore, research on establishing a new set of design activities that will reduce the development the life cycle (LC) of military equipment development is relevant. **The subject** of the study is the development of analytical and simulation models that make it possible to analyze and plan the necessary project activities to reduce the LC of high-tech products (UAVs). The purpose of the study is to create a set of mathematical and simulation models that enable the formation of a new product architecture, the optimization of key project indicators, and defining project activities aimed at LC reduction under limited capabilities. **The tasks** addressed include: systematically analyzing the LC of developing a high-tech product with a focus on its reduction; creating a new method for forming the product architecture using a component-based approach; establishing parallel design processes that will ensure LC reduction; optimizing the time, cost, and risks of project activities under resource constraints; modelling of the proposed activities for LC reduction in the development of a high-tech product (UAV). The research utilizes a range of **mathematical methods and models**, including: system analysis for establishing the sequence of project activities that ensure LC reduction; a model of component-based representation of the new product architecture; a method for selecting a rational design variant using lexicographic ordering; a model for optimizing time and cost under acceptable project risks; agent-based simulation of the sequence of project activities to ensure LC reduction for new equipment development. The following **results** were achieved: a system representation of project activities for LC reduction was proposed; a component architecture of the new product was substantiated; the basic architecture was adapted to the requirements of developing new equipment; a set of possible design variants for creating new equipment was generated, with the selection of a rational one; time and cost optimization was conducted within acceptable levels of project risk; and a simulation of the sequence of project activities was performed. **Conclusions:** the proposed approach makes it possible to justify project activities for reducing the development LC of new equipment, enabling the rapid production of relevant systems under the special conditions of the country. **The scientific novelty** of the approach lies in the scientific justification of project activities for LC reduction using a component-based method and the parallel execution of design processes, which ensures the rapid development of military equipment and enables the mass production of relevant systems for the frontline.*

Keywords: rapid creation of new technology; life cycle of complex product creation; component architecture; parallel design processes; time and cost optimization; design risks; limited capabilities; simulation modeling.

1. Introduction

The current state of the country has led to an urgent need for the development and serial production of new military equipment to ensure the successful execution of defense tasks [1, 2]. However, the existing approaches to the creation of military equipment, including UAVs, are oriented toward a long life cycle (LC) of development, which does not allow the formation of the required quantity of modern weaponry needed to create asymmetry in the enemy's military actions. It is neces-

sary to analyze all stages of the LC with the aim of reducing them under the specific conditions the country is facing [3, 4]. Therefore, there emerges a relevant task of conducting research aimed at shortening the LC, which will make it possible to transition to the serial production of various types of UAVs that constitute a key innovative element of modern hybrid warfare.

1.1. Motivation

The analysis of existing design activities related to the creation of UAVs has demonstrated the need to



identify opportunities for reducing each individual stage of the life cycle (LC), which will subsequently lead to a reduction of the overall cycle [5, 6]. In this way, it will become possible to rapidly transition to the serial production of high-tech products, ensuring mass and scalable manufacturing [7]. However, the existing approaches to the development of modern equipment do not allow for a comprehensive reduction of the LC [8, 9]. Therefore, there is a need to formulate and scientifically substantiate a new approach, as well as new methods and models, that will make it possible to shorten the LC and ensure the rapid creation of new military equipment under the limited capabilities imposed by the country's special state.

1.2. State of the Art and problem statement

There exists a range of problems in the development of modern new equipment, the resolution of which will enable the formation of the necessary defence potential of the country under conditions of the enemy's aggressive actions. Some of these problems are in the process of being solved, but new ones have also emerged that require further research. Let us consider several studies in the areas listed below:

1. Development of a new component-based architecture of the product, which will allow the formation of a set of relatively isolated components whose composition depends on the direction of the product's application.

In [10], the use of a scientific and methodological framework for multi-criteria selection is presented for determining the composition of onboard equipment of combat aircraft in order to expand their combat capabilities through modernization. A scientific and methodological approach is proposed for identifying, within a multi-criteria space, the resulting set of variants of onboard equipment configurations for combat aircraft undergoing modernization. The authors of [11] present a multi-purpose system architecture for autonomous platforms with multiple UAVs. Based on this architecture, a framework has been developed that enables developers to ensure rapid prototyping of autonomous systems involving multiple UAVs.

2. Formation of a new sequence of design activities for creating an innovative product.

The articles [12, 13] is devoted to analyzing the factors that influence the effectiveness of design decisions in modern conditions of rapid digitalization. Emphasis is placed on the necessity of considering such variables as the quality of planning, the innovativeness of the applied technologies, the rational use of resources, and the ability to adapt to unpredictable risks. A comparative SWOT analysis makes it possible to identify the advantages and disadvantages of different

project implementation options, taking into account factors such as work duration, cost, resource availability, and environmental impact. This enables the identification of internal strengths and weaknesses of the project, as well as external opportunities and threats.

3. Seeking a compromise between reducing the time required to develop a high-tech product, project costs, and associated risks.

In [14], the authors apply a hybrid method that integrates the fuzzy analytical hierarchy process and a fuzzy method of multi-criteria optimization and compromise decision-making, while examining the most influential and conflicting criteria related to economic, environmental, social, and risk-based aspects. Linguistic variables are used in the decision-making process to reduce the uncertainty of criterion weights. In [15], a multi-criteria decision-making model based on robust compromise (RoCo) is proposed, which employs non-linear programming and is solved using genetic algorithms.

4. Scientific substantiation of new approaches to the rapid development of modern equipment, especially military equipment.

The article [16] examines the transformative role of small, low-cost unmanned aerial vehicles in future wars, drawing on lessons learned from recent military operations and emphasizing their relevance for force planning. The importance of using artificial intelligence and autonomous drones to protect critical infrastructure is emphasised. In the defence sector, the potential of 3D printing has revolutionized the production of weapons and equipment [17]. The adaptation of components to the specific requirements of a mission increases the effectiveness of military operations while simultaneously reducing the costs associated with mass production.

5. Acceleration of testing innovative products for military needs.

To assess the reliability of military equipment under near-limit conditions, the application of a mathematical model of boundary-value testing has been proposed [18]. The scenarios developed within this model include verifying the compliance of the tactical and technical characteristics of a prototype of military equipment, predicting possible failures, and evaluating the impact of each level on the overall reliability of the system. Boundary-value testing helps enhance the efficiency and reliability of the evaluation process for military equipment prototypes. The authors of [19] have developed the structure of an automated system that incorporates global experience in technical solutions through comprehensive analysis of technology readiness levels. This system objectively determines the percentage of compliance with technology readiness requirements with high accuracy for the implementation of technologies and prototypes of weapons and military equipment.

6. Reduction of technological preparation time for production using modern information technologies.

The article [20] is devoted to the experience of JSC “Motor Sich” in creating and implementing an integrated system for the technological preparation of production of new aircraft engines, which includes a set of interrelated automated subsystems. The implementation of the integrated system has made it possible to reduce the technological preparation time for production by up to 33%. The authors of [21] propose a method for using artificial neural networks to automate the technological preparation process. It is demonstrated that the use of this software tool in production significantly increases efficiency while maintaining optimal calculation accuracy.

7. Formation of serial production based on virtual distributed management using modern robotic processes.

The requirements for organizing new production facilities in accordance with the Industry 4.0 concept have led to the creation of enterprises in the form of virtual manufacturing systems focused on the development of new innovative products. In [22], models for the rational placement of a virtual production facility under conditions of limited enterprise capabilities are developed. The modeling of the production cycle is carried out taking into account time delays and queues that occur during the execution of technological operations. The article [23] examines a systems approach to establishing robotic production for small nano-class spacecraft to ensure their serial manufacturing. An intelligent production cell is described as the fundamental element of matrix-type serial robotic manufacturing.

8. Establishing resilient production of modern equipment under conditions of threat exposure.

The authors of [24] model potential costs associated with ensuring the resilience of an enterprise under risks of possible threats (political-economic, climatic, terrorist, and military). A simulation model is developed to study the effects of threats and resulting losses, enabling preventive actions to ensure enterprise stability. The article [25] presents research results on key risks related to the implementation of projects for supplying weapons and military equipment during modern warfare, providing an analysis of the probability of these risks occurring and the potential consequences of their realization. The most critical risks that may lead to failure of such projects are identified. In the article, supply projects are understood as measures related to the development, production, and procurement of weapons and military equipment for the needs of the Armed Forces of Ukraine.

This is not a complete list of problems, which continue to expand under the conditions of modern hybrid warfare, indicating the relevance of conducting research

aimed at reducing the life cycle of new equipment development to enable the rapid production of current military products. This work presents solutions addressing a portion of the aforementioned problems.

1.3. Objectives and methodology

A contradiction arises between the need for the rapid production of high-tech products (UAVs) under conditions of their serial manufacturing for the country’s defence needs, and the lack of improved or sufficiently developed methods, models, and information technology that would make it possible to shorten the life cycle of creating products required for successful military missions involving UAVs.

The **purpose** of the study is to develop a method and models that enable the reduction of the life cycle of creating relevant products for frontline needs and to ensure their serial production under the limited capabilities and threats imposed by the country’s wartime situation.

In accordance with the stated research objective, it is necessary to solve the following tasks:

1. Perform a system analysis of the life cycle of creating a high-tech product (UAV), with the possibility of its subsequent reduction.
2. Develop a component-based design method for modern high-tech products (UAVs) that enables adaptation to evolving battlefield conditions.
3. Create a new scheme of design activities for the rapid development of an innovative product (UAV).
4. Optimize time, risk, and cost to ensure the fast creation of a new product (UAV).
5. Conduct agent-based modeling of the sequence of design activities aimed at structuring and shortening the life cycle of developing a high-tech product (UAV).

The article is structured as follows:

Section 2 is devoted to a system analysis of actions aimed at the rapid creation of a high-tech product (UAV) by shortening its life cycle.

Section 3 concerns the application of the component-based design method for creating relatively isolated components that together form a new architecture of the innovative product (UAV).

Section 4 presents the formation of design activities for creating a new product (UAV) in the directions of synthesizing a basic architecture and adapting it to a specific type of equipment.

Section 5 is related to the formation of an optimization model for assessing the reduction of life cycle time using constraints related to project cost and risks.

Section 6 is dedicated to the development of an agent-based model for simulating the shortening of the life cycle of creating a high-tech product (UAV) for rapid production.

Section 7 contains a discussion of the scientific results and their presentation in the form of a methodology that highlights the significance of the conducted research for practical application.

Section 8 concludes the article by summarizing the findings, outlining prospects for further research, and addressing the development of an applied information technology for planning design activities under conditions of a shortened life cycle for creating new equipment (UAVs).

2. System analysis of the life cycle of developing a high-tech product (UAV)

Under conditions of hybrid warfare, the serial production of military equipment (drones, missiles, etc.) plays a critical role. New (innovative) high-tech products can create asymmetry in combat operations, enabling the formation of the necessary defensive potential to counter the enemy's offensive actions. Therefore, research into modelling the reduction of the life cycle (LC) for developing high-tech products is of great relevance.

To achieve this, it is necessary to:

- establish a systematic sequence of actions for reducing the life cycle of high-tech products (UAVs) to ensure the rapid production of required items for the frontline;
- develop a new architecture for a complex product (UAV) using relatively isolated components;
- perform optimization of design activities using indicators of time, cost, and project risks;
- create a simulation model to analyze, over time, the formed sequence of design activities under conditions of life cycle reduction.

Existing approaches are oriented toward forming the life cycle of high-tech products under peacetime conditions. However, given the current situation in the country, it is critically important to rapidly develop and serially produce relevant products for the frontline (weapons, ammunition, etc.). Therefore, research has been conducted on reducing both individual LC stages and the overall cycle of developing high-tech products using modern design technologies.

At the stage of synthesizing the architecture of a high-tech product (for example, drones), it is proposed to use a modern component-based approach for rapid product creation using typical components (existing ones with positive operational experience; modernized components; and new, innovative components). The greatest risks, as well as increases in time and cost, are associated with the innovative components. Therefore, an optimization model was developed to identify a rational variant of the architecture of a high-tech product using a compromise between project risks, time, and

costs. A multivariate analysis of possible configurations of the high-tech product was performed to identify a rational option for project planning. In the optimization models, a lexicographic ordering method was proposed, which allows the use of both quantitative and qualitative indicator assessments. When the number of variants was large, the method of integer (Boolean) programming was employed.

For the stage of technological preparation for production, it is reasonable to use modern 3D printers, which allow rapid fabrication of individual components of military equipment. The long testing stage, which existed in the past, has been shortened by conducting trials directly under combat conditions on the battlefield.

For serial production and its scaling, it is necessary to use a virtual cloud environment for distributed manufacturing control.

Simulation modelling makes it possible to analyze the management and formation of the life cycle of developing a high-tech product (UAV) using the multi-agent Any Logic environment.

The following mathematical methods and models were proposed, which make it possible to:

- perform a system analysis of LC reduction and identify critical factors;
- create a model for component-based synthesis of the architecture of a high-tech product using typical components;
- develop a model for optimizing project time and risk to select a rational project implementation scenario;
- form a model of virtual distributed control for serial production of high-tech products;
- conduct simulation and agent-based modelling of the sequence of LC stages.

Thus, the proposed approach makes it possible, at the early stages of developing high-tech products, to analyze the product life cycle and ensure its reduction, especially in the stages of component architecture formation, technological preparation, and serial production. This enables the serial manufacturing of innovative products. The overall defensive potential will contribute to creating asymmetry in combat operations against the enemy. The studies presented in the sections of the work provide scientific substantiation for a new approach to the rapid development of high-tech products, based on component-based design, reduction of technological preparation, and battlefield testing.

3. Component-based method for designing modern high-tech products (UAVs)

Innovative technologies of modern warfare have created the necessity to develop a new architecture for

complex systems (UAVs) that can rapidly adapt to changing conditions of military operations. Existing approaches are based on the traditional design paradigm, where a new product is developed almost from scratch. This does not allow for the rapid creation of innovative products and does not meet the urgent needs of the military. Therefore, a design method based on a component-based approach has been developed. In this method, a set of relatively isolated components is formed, from which the product architecture can be constructed as a combination of their configurations. It is proposed to form a basic architecture of a high-tech product (UAV), consisting of three main types of components:

- existing components used in analogous systems and proven to be effective in technological applications;
- components that require modernization based on existing solutions, enabling their adaptation to new operational conditions;
- new, innovative components that do not currently exist but must be developed to meet the requirements of the technical specification.

Thus, the structure of the architecture of a new innovative product (UAV) can be represented as a tuple of sets:

$$A = \langle A_1, A_2, A_3 \rangle, \quad (1)$$

where A_1 – the set of existing components;

A_2 – the set of modernized components;

A_3 – the set of innovative components.

It should be noted that the ratio of the sets A_1 , A_2 , and A_3 within the composition of a high-tech product (UAV) determines the time, cost, and risks of the project related to the development of a new type of complex system (for example, interceptor drones).

The following project situations are possible:

1. The product consists mainly of components from set A_1 . Components from sets A_2 and A_3 are minimally used in the product (UAV) architecture. This ensures rapid development of the high-tech product, but its innovativeness and effectiveness under modern warfare conditions will be very low. The development time (T), project cost (W), and risks (R) will be minimal.

2. The product consists primarily of components from sets A_2 and A_3 . Innovative components from set A_1 are used to a limited extent. A significant number of components require modernization. This leads to an increase in development time (T), cost (W), and project risks (R).

3. The product consists mainly of components from sets A_2 and A_3 . Components from set A_1 are used minimally. This results in a further increase in development time (T), cost (W), and project risks (R).

Such a configuration may become unacceptable due to constraints on time (T), cost (W), and project risks (R).

4. The product consists predominantly of innovative components from set A_3 . Components from sets A_1 and A_2 are scarcely present. This greatly increases development time (T), project cost (W), and risks (R). Such a situation may lead to the impossibility of completing the project.

Thus, depending on the ratio of the sets A_1 , A_2 , and A_3 , different scenarios for creating new equipment (UAVs) arise. Excessive innovativeness may lead to the impossibility of developing new equipment under the current conditions in the country. Therefore, a complex task emerges – finding a compromise among the indicators (T, W, R), under limited capabilities, to ensure the rapid creation of relevant defence products (for example, UAVs).

Let us assume that it is possible to form a set of alternative variants for identifying a compromise solution among the indicators (T, W, and R). We will use the lexicographic ordering method, which makes it possible to select a rational project implementation option for developing a new high-tech product (UAV). In the lexicographic ordering method, different metrics (qualitative and quantitative) may be used to evaluate the indicators (T, W, and R).

Let us consider an illustrative example of selecting a rational variant for creating a new product (UAV) using a component-based architecture. The evaluation of time (T) and project cost (W) will be performed in a quantitative metric, while risks (R) will be represented qualitatively. For qualitative assessments, we introduce the linguistic variable y_{jk} :

$$y_{jk} = \begin{cases} A - \text{minimum risk if, for the } j\text{-th variant,} \\ \text{the } k\text{-th UAV architecture configuration} \\ \text{was selected with predominant use of} \\ \text{components } A_1; \\ B - \text{moderate risk if, for the } j\text{-th variant,} \\ \text{the } k\text{-th UAV architecture configuration} \\ \text{was selected with predominant use of} \\ \text{components } A_1, A_2; \\ C - \text{acceptable risk if, for the } j\text{-th variant,} \\ \text{the } k\text{-th UAV architecture configuration} \\ \text{was selected with predominant use of} \\ \text{components } A_2, A_3; \\ D - \text{very high risk if, for the } j\text{-th variant,} \\ \text{the } k\text{-th UAV architecture configuration} \\ \text{was selected with predominant use of} \\ \text{components } A_3. \end{cases} \quad (2)$$

For the time indicator (T), the largest value is 12 months. For the project cost indicator (W), the largest value is 1 million UAH. Let us represent the importance of the indicators (T, W, and R) in the form of a priority sequence:

$$T, R, W, \quad (3)$$

where the development time of the new product is placed first, as it is the most critical factor for ensuring production speed.

Let us assume that we have ten possible variants for creating a new high-tech product (UAV), each based on a different composition of components (A□, A□, A□).

$$\begin{array}{ll} 1. 8 \text{ C } 750 & 6. 9 \text{ C } 600 \\ 2. 6 \text{ D } 1000 & 7. 12 \text{ A } 350 \\ 3. 9,5 \text{ B } 550 & 8. 10 \text{ B } 450 \\ 4. 8,5 \text{ C } 700 & 9. 11 \text{ A } 400 \\ 5. 7 \text{ D } 800 & 10. 10 \text{ B } 500 \end{array} \quad (4)$$

Let us lexicographically order the variants:

$$\begin{array}{ll} 2. 6 \text{ D } 1000 & 3. 9,5 \text{ B } 550 \\ 5. 7 \text{ D } 800 & 8. 10 \text{ B } 450 \\ 1. 8 \text{ C } 750 & 10. 10 \text{ B } 500 \\ 4. 8,5 \text{ C } 700 & 9. 11 \text{ A } 400 \\ 6. 9 \text{ C } 600 & 7. 12 \text{ A } 350 \end{array} \quad (5)$$

We will exclude the variants with extremely poor values of the indicators (T, W, R). We obtain:

$$\begin{array}{ll} 1. 8 \text{ C } 750 & \\ 4. 8,5 \text{ C } 700 & \\ 6. 9 \text{ C } 600 & \\ 3. 9,5 \text{ B } 550 & \\ 8. 10 \text{ B } 450 & \\ 10. 10 \text{ B } 500 & \\ 9. 11 \text{ A } 400 & \end{array} \quad (6)$$

From this, it follows that if time (T) is used as the most important indicator for the project of creating a new product (UAV), the first variant is the optimal choice.

Thus, this section has presented a new method for designing a complex product (UAV) based on a component-oriented approach. It has been demonstrated that different configurations of the component composition (existing, modernized, and innovative) within the product architecture make it possible to form multiple variants of the component architecture. The selection of a rational variant, using the indicators of time, cost, and risk, was carried out using the lexicographic ordering of variants.

4. A new scheme of design activities for the rapid development of an innovative product (UAV)

Existing methods for developing complex products generally rely on executing a sequence of design activities in which the product is created almost from scratch. The component-based approach proposed in Section 3 enables the execution of parallel project activities when developing a high-tech product (UAV). Let us define two parallel directions of project activities:

- the first direction is associated with the formation of a basic architecture of the product with a unified set of components. This architecture will later be used to create new types of equipment;

- the second direction concerns the development of a specific type of new equipment in the selected field of application (for example, drones). This requires performing project activities related to adapting the basic architecture and modernizing existing components to meet the requirements of the new product.

Within the basic UAV architecture, the components requiring modernization are identified, and new components necessary for the development of the high-tech product are defined. The personnel structure of the project consists of two teams. The first team forms and improves the basic product architecture, while the second team performs work related to the development of the specific type of equipment (for example, interceptor drones).

The sequence of design activities for creating and improving the basic architecture of a complex product is presented in Fig. 1.



Fig. 1. Scheme for developing the basic architecture of a complex product

Here:

P1 – formulation of project requirements for developing a typical product;

P2 – formation of the basic component architecture of the typical product;

P3 – development of unified components;

P4 – integration of unified components considering the basic product architecture;

P5 – testing of the prototype;

P6 – development of standard technological processes.

The second direction is focused on modernizing the basic product architecture to create a new type of equipment (for example, interceptor drones). Within the structure of the new architecture, the components that

require modernization are identified, as well as the new components that must be developed.

Figure 2 presents the sequence of project activities for creating the new product, which includes both the modernization of existing components and the development of new ones (Fig. 2).

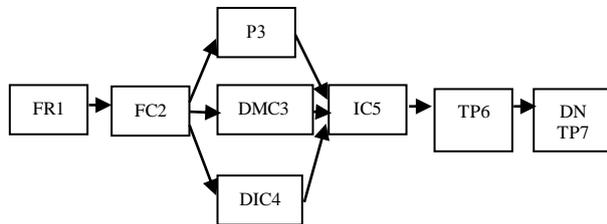


Fig. 2. Scheme of work for developing a new type of equipment

Here:

FR1 – formulation of requirements for the project of creating a new product;

FC2 – formation of the component-based architecture of the new product;

DMC3 – development of modernized components;

DIC4 – development of innovative components;

IC5 – integration of components into the architecture of the new product;

TP6 – testing of the prototype of the new product;

DNTP7 – development of new technological processes.

Thus, the proposed new scheme of design activities is carried out by two teams of designers. This approach offers several advantages over existing methods:

- the formation and improvement of the basic product architecture, which serves as the foundation for creating new products in the selected domain (UAVs);

- the use of two development teams working in parallel: the first develops the basic architecture of the product, while the second designs a specific type of new equipment;

- the parallel work of the development teams reduces the duration of the project for creating new equipment;

- the reduction of the life cycle for developing new equipment at the initial stages associated with forming the component-based architecture.

Thus, this section has proposed a new scheme of design activities that employs a component-based representation of the new product and incorporates two parallel directions of work for the design teams (the creation and refinement of the basic product architecture, and the development of a specific type of new product). This makes it possible to shorten the life cycle of developing high-tech products and ensure, in the future, the rapid production of relevant equipment for military defense operations.

5. Optimization of time, risks, and cost to ensure the rapid development of a new product (UAV)

The reduction of the life cycle (LC) for developing high-tech products (UAVs) is fundamental for ensuring the rapid production of relevant equipment under the country’s special wartime conditions. A multi-stage LC requires finding rational solutions to shorten the duration of each stage. However, limited resource capabilities do not allow full implementation of measures to shorten all LC stages. Therefore, a relevant task arises—identifying a rational (optimal) variant for executing actions related to the development of a new product under restricted conditions.

Let us construct an optimization model for identifying a rational variant of LC reduction using the method of integer (Boolean) programming. Let us introduce the Boolean variable x_{ie} , which has the following values:

$$x_{ie} = \begin{cases} 1, & \text{if, for the } i\text{-th LC stage,} \\ & \text{the reduction was carried out} \\ & \text{using the } e\text{-th set of actions;} \\ 0, & \text{otherwise.} \end{cases} \quad (7)$$

Key indicators for evaluating the actions aimed at reducing the LC of developing a high-tech product (UAV):

- time of LC reduction (T);
- cost of implementing reduction measures (W);
- risks associated with the execution of project activities (R).

Using the Boolean variable x_{ie} , the indicators (T, W, and R) take the following formal form:

$$\begin{aligned} T &= \sum_{i=1}^M \sum_{e=1}^{n_i} t_{ie} x_{ie}, \\ W &= \sum_{i=1}^M \sum_{e=1}^{n_i} w_{ie} x_{ie}, \\ R &= \sum_{i=1}^M \sum_{e=1}^{n_i} r_{ie} x_{ie}, \end{aligned} \quad (8)$$

where M is the number of LC stages considered for reduction;

n_i is the number of possible action variants for reducing the i-th LC stage;

t_{ie} is the time required to perform the e-th set of actions for reducing the i-th LC stage;

w_{ie} is the cost of performing the e-th set of actions for reducing the i-th LC stage;

r_{ie} is the risk associated with performing the e -th set of project actions for reducing the i -th LC stage.

As the primary indicator for LC reduction, we will use the project time (T), which must be minimized:

$$\min T, T = \sum_{i=1}^M \sum_{e=1}^{n_i} t_{ie} X_{ie}, \quad (9)$$

under the constraints of project cost (W) and project risk (R):

$$\begin{aligned} W &\leq W', W = \sum_{i=1}^M \sum_{e=1}^{n_i} w_{ie} X_{ie}, \\ R &\leq R', R = \sum_{i=1}^M \sum_{e=1}^{n_i} r_{ie} X_{ie}, \end{aligned} \quad (10)$$

where W' , R' is the admissible values of the project cost and project risks for developing the new equipment.

The solution of the presented optimization problem can be carried out using the following approaches:

- a complete enumeration of all possible variants, when their number is small;
- the branch-and-bound method (or its modification), when the number of variants is large;
- a randomized method, when the number of variants is very large (aimed at improving the value of the objective function).

Thus, this section has formulated and solved the relevant task of reducing the LC of creating a new high-tech product under conditions of limited project cost and risk. An optimization model has been developed for determining the rational set of design actions to shorten each stage of the LC, thereby ensuring the reduction of the overall cycle. This enables, in the future, the rapid development of high-tech products (UAVs) under the constrained conditions of the country's wartime state.

6. Agent-based modelling of the sequence of design activities for structuring and reducing the life cycle of developing a high-tech product (UAV)

To study the reduction of the life cycle (LC) for developing a high-tech product (UAV), an agent-based simulation model was developed using the Any Logic platform. The model makes it possible to evaluate potential options for LC reduction by selecting different sets of design actions at individual LC stages. For each possible variant of design actions, the model assesses the project time (T), cost (W), and risk (R). The set of agents enables the formation of various scenarios for

implementing actions aimed at reducing the LC of developing a high-tech product:

1. Formation of the component composition of the high-tech product architecture using existing, modernized, and innovative components (agent "composition formation").
2. Selection of design activities for the R&D stage (agent "R&D").
3. Selection of design activities for prototype testing (agent "testing").
4. Selection of design activities for production preparation (agent "production preparation").
5. Selection of actions for launching serial production (agent "serial production").
6. Simulation of the time required to perform design activities at each LC stage (agent "time simulation").
7. Simulation of project risks for each LC stage (agent "project risk").
8. Simulation of the cost of project activities at each LC stage (agent "cost").
9. Optimization of LC duration for creating new equipment under constraints on project cost and risk (agent "optimization").
10. Assessment of the LC reduction level for the new equipment (agent "LC reduction").
11. Management of the scenario of actions related to LC reduction (agent "management").
12. Generation of results of the LC reduction simulation for the new equipment (agent "results").

Figure 3 presents the structural diagram of the multi-agent model used to study LC time reduction in the development of high-tech equipment (UAV).

As a result of the simulation, the following output data are generated:

- the time required to perform the tasks at each LC stage;
- the cost of performing the tasks at each LC stage;
- the risks associated with performing the tasks at each LC stage;
- the overall values of project time, cost, and risks after LC reduction;
- the percentage reduction of the LC.

Thus, in this section, a multi-agent model has been developed that makes it possible to investigate various scenarios for reducing the life cycle of developing a high-tech product (UAV) under the existing constraints imposed by the country's current conditions.

7. Discussion

The needs of the frontline have become critically acute due to the lack of a sufficient range of modern military equipment capable of creating asymmetry on

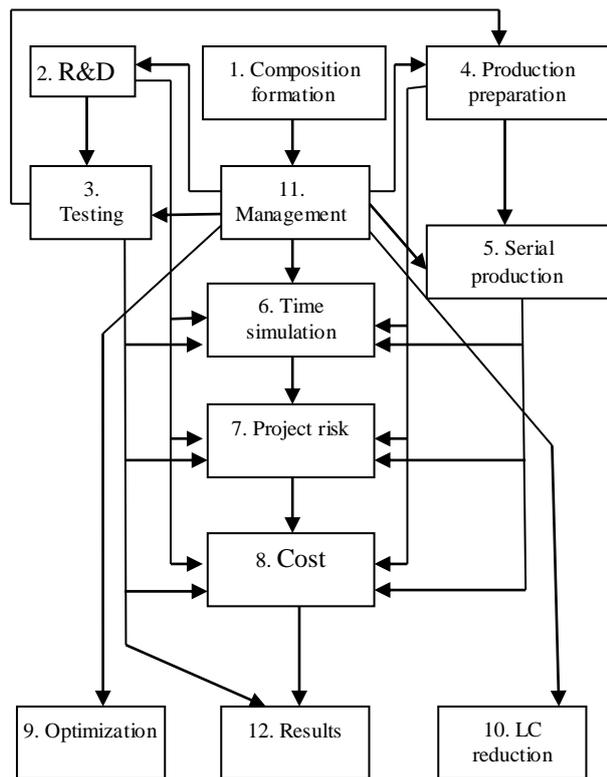


Fig. 3. Structural diagram of the multi-agent model

the battlefield through its innovative characteristics. However, in order to develop high-tech products (UAVs) and ensure their rapid production during wartime, it is necessary to shorten the life cycle of creating relevant equipment. In this work, a system analysis of actions aimed at reducing the LC under the country's special wartime conditions has been conducted. It has been concluded that modern approaches must be used for the rapid development of the architecture of a new product (UAV). Therefore, a component-based approach has been proposed, which, taking into account unified components, allows the formation of an appropriate product architecture for subsequent transition to serial production. The main types of components have been identified (existing, modernized, innovative), from which a new product can be created in a specific application domain. It has been shown that the use of these components within a high-tech product directly influences the time, cost, and risks associated with developing the new system. Creating a product solely from existing components (analogues) cannot significantly improve its characteristics. On the other hand, developing equipment primarily from innovative components may significantly increase project time, cost, and risks. Therefore, it is necessary to find a compromise depending on the importance of the indicators (time, cost, risks). To address this, the lexicographic ordering method has been proposed to identify the most suitable vari-

ant for developing the new product, allowing the use of both qualitative and quantitative metrics. Furthermore, to accelerate the development of a new product, two parallel design directions were proposed:

- creating the basic product architecture based on unified components;
- adapting existing components to the technical requirements through their modernization;
- developing new components that are not present among the existing ones.

This enabled the design teams to carry out parallel development processes for the creation of the new product (UAV).

Under constrained conditions for rapidly developing new equipment in the country's wartime environment, it is necessary to optimize the time required for design activities while satisfying cost and acceptable risk restrictions. Therefore, an optimization model was developed using integer (Boolean) programming to select a rational combination of design actions at individual LC stages, enabling a reduction of the overall LC.

A simulation model was developed in the form of a multi-agent environment to analyze various scenarios of LC reduction actions under time, cost, and risk constraints.

The developed set of models is aimed at studying the process of LC reduction to enable the rapid development of military equipment. This makes it possible to conclude that the proposed approach is both timely and effective, enabling the rapid creation of new equipment and subsequently ensuring scalability and mass production of relevant military products.

Future research will focus on developing an applied information technology for modelling the sequence of design activities that support LC reduction in the development of new equipment (UAVs) and ensure its rapid production, thereby contributing to the success of military missions and strengthening the country's defense capability.

8. Conclusions

The conducted research enables the planning of design activities aimed at reducing the life cycle of developing high-tech products (UAVs), namely:

- forming a modern component-based architecture of a new product using three types of components (existing, modernized, and innovative);
- presenting a set of possible variants for developing the product in order to select a rational one;
- identifying a compromise variant for designing a high-tech product using the indicators of time, cost, and project risks;
- organizing parallel processes for developer teams to create the new product and reduce the LC;

- developing a unified component-based basic architecture of the product (UAV);
- adapting the product architecture to create the required new type of equipment (UAV) relevant to modern wartime conditions;
- optimizing the development time of the new product by reducing the duration of individual LC stages;
- performing simulation modelling of the sequence of design activities over time to evaluate LC reduction.

The novelty of the proposed approach lies in the scientific substantiation of design activities aimed at reducing the life cycle of developing high-tech products (UAVs), achieved through the creation of an integrated system of systemic, optimization, and simulation models. This system enables the planning of design actions for developing new types of equipment under the limited capabilities imposed by the country's special wartime conditions.

Thus, the main conclusion (the main contribution) of the study is the following:

The proposed system of models enables the justification of LC reduction, the selection of an appropriate product architecture (UAV), the determination of the component composition required for the new product, the optimization of project time, cost, and risks, and the substantiation of the sequence of design activities for reducing the LC. This, in turn, makes it possible to transition to the rapid development of new equipment, ensure mass production, and achieve scalable manufacturing.

Therefore, the conducted research on reducing the life cycle of high-tech product development (UAVs) provides a solution to the urgent task of creating new types of military equipment, which will enable the formation of military parity on the battlefield.

Contribution of authors: system analysis of life cycle reduction for new equipment development – **O. Ye. Fedorovich**; formation of the sequence of actions for creating a new product – **A. V. Popov**; formation of product architecture – **T. S. Pisklova**; formation of the optimal composition of a product component – **L. V. Malieiev**; optimization of project time and costs – **A. V. Rybka**; simulation modelling of the sequence of project actions – **V. A. Fedorovich**.

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

The study was supported by the Ministry of Education and Science of Ukraine project No. 0125U001562.

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. Gorbulin, V. P., & Mosov, S. P. Tendentsiyi dronenizatsiyi v Ukrayini na suchasnomu etapi [Current trends in droneization in Ukraine]. *Visnyk Natsional'noyi akademiyi nauk Ukrayiny – Visnyk of the National Academy of Sciences of Ukraine*, 2024, no. 12, pp. 40-48. DOI: 10.15407/vsn2024.12.040. (In Ukrainian).
2. Semenenko, O., Lipskyi, A., Hetman, A., Reznik, V., Herasymenko, O., & Tarasov, R. Osnovni teoretychni aspekty vyznachennya kryteriyiv viys'kovoekonomichnoyi efektyvnosti v zadachakh obgruntuvannya vyboru ratsional'nykh variantiv skladnykh zrazkiv ozbroynennya ta viys'kovoyi tekhniky [The main theoretical aspects of determining the criteria of military and economic efficiency in the tasks of justifying the choice of rational options for complex types of weapons and military equipment]. *Social Development and Security*, 2023, vol. 13, no. 2, pp. 171-184. DOI: 10.33445/sds.2023.13.2.15. (In Ukrainian).
3. Sokulsky, O., Chumakevych, V., & Topolskov, Ye. Stan rozroblennya ta perehlyadu standartiv systemy upravlinnya zhyttyevym tsyklom ozbroynennya ta viys'kovoyi tekhniky [Statuse of development and review of standards for the lifecycle management system of weapons and military equipment]. *Problemy stvorennya, testuvannya, zastosuvannya ta ekspluatatsiyi skladnykh informatsiynykh system – Problems of construction, testing, application and operation of complex information systems*, 2025, no. 1(28), pp. 160-176. DOI: 10.46972/2076-1546.2025.28.14. (In Ukrainian).
4. Setiawan, B., Wardhana, E., Alamie, N. & Parianom, R. Life Cycle Cost Calculation Model Main Tools of the Weapon System Indonesian National Army. *Journal of Lifestyle and SDGs Review*, 2025, no. 5(3), article no. 3872. DOI: 10.47172/2965-730X.SDGsReview.v5.n03.pe03872.
5. Moro, N. Life cycle of a Military Product. *Scientific Bulletin-Nicolae Balcescu Land Forces*

Academy, 2018, vol. 23, no. 2, pp. 103-111. Available at: https://www.armyacademy.ro/buletin/bul2_2018/Moro.pdf (accessed September 04, 2025).

6. Zikos, Th., Karadimas, N. V., Tsigkas, A., & Sidiropoulou, K. Weapons' life cycle cost: the key of success in logistics. *WSEAS Transactions on Business and Economics*, 2022, no. 19, pp. 1036-1045. DOI: 10.37394/23207.2022.19.91.

7. 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](https://doi.org/10.32620/reks.2021.1.13).

8. Markard, J. The life cycle of technological innovation systems. *Technological Forecasting and Social Change*, 2020, vol. 153, article no. 119407. DOI: 10.1016/j.techfore.2018.07.045.

9. Zamelek, P. Prospects for the application of systems engineering in the military equipment acquisition process. *Rocznik Bezpieczeństwa Morskiego*, 2024, no. 18, pp. 725-753. DOI: 10.5604/01.3001.0054.8311.

10. Artushyn, L., Kononov, O., & Yerko, V. Vyznachennya rezul'tuyuchoyi mnozhyny variantiv pry bahatokryteriyomu vybori skladu bortovoho obladdannannya boyovykh litakiv dlya yikh modernizatsiyi [Determination of the resulting set of options at the multi-criteria selection of the on-board equipment of combat aircraft for their modernization]. *Zbirnyk naukovykh prats' Derzhavnogo naukovo-doslidnogo instytutu aviatsiyi – Collection of scientific works State Research Institute of Aviation*, 2021, no. 17 (24), pp. 20-26. DOI: 10.54858/dndia.2021-17-3. (In Ukrainian).

11. 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.

12. Chertkov, O. Yu., Shumak, L., & Rasputnyi, D. Analiz faktoriv vplyvu na efektyvnist' proektnykh rishen' [Analysis of factors influence on the efficiency of design solutions]. *Shlyakhy pidvyshchennya efektyvnosti budivnytstva – Ways to improve construction efficiency*, 2024, no. 2(53), pp. 123-141. DOI: 10.32347/2707-501x.2024.53(2).123-141. (In Ukrainian).

13. Shpakov, A. V., Shcherban, B. M., Tsymbalisty, Y. V., Gergi, M. S., & Katsyuba, I. R. Naukovo-analitychni komponenty otsinky ta vybir al'ternatyvnykh variantiv vprovadzhennya developers'koho proektu na peredinvestytsiyno-pidhotovchu fazu tsykladu [Scientific-analytical components of assessment and selection of alternative options for imple-

menting a development project in the pre-investment and preparatory phase of the cycle]. *Shlyakhy pidvyshchennya efektyvnosti budivnytstva – Ways to improve construction efficiency*, 2023, no. 2(52), pp. 325-344. DOI: 10.32347/2707-501x.2023.52(2).325-344. (In Ukrainian).

14. Wang, C. N., Nguyen, N. A. T., Dang, T. T., & Lu, C. M. A Compromised Decision-Making Approach to Third-Party Logistics Selection in Sustainable Supply Chain Using Fuzzy AHP and Fuzzy VIKOR Methods. *Mathematics*, 2021, vol. 9, no. 8, article no. 886. DOI: 10.3390/math9080886.

15. Wanke, P., Tan, Y., Antunes, J., & Emrouznejad, A. Foreign direct investment performance drivers at the country level: a robust compromise multi-criteria decision-making approach. *Technological and Economic Development of Economy*, 2024, no. 30(1), pp. 148-174. DOI: 10.3846/tede.2024.19532.

16. Renic, M., & Christensen, A. Air Power by Small, Low-Cost Drones: Implications for Future Warfare. Shift Paradigm. *The Air Power Journal, Fourth Edition*, 2024. Available at: <https://theairpowerjournal.com/air-power-by-small-low-cost-drones-implications-for-future-warfare/> (accessed November 09, 2025).

17. Adeleke, A. K., Montero, D. J. P., Lottu, O. A., Ninduwezuor-Ehiobu, N., & Ani, E. C. 3D printing in aerospace and defense: A review of technological breakthroughs and applications. *World Journal of Advanced Research and Reviews*, 2024, vol. 21, no. 2, pp. 1149-1160. DOI: 10.30574/wjarr.2024.21.2.0558.

18. Zasadko, A., Lytovchenko, V., Raksha, V., Shvets, S., & Yula O. Model' testuvannya viys'kovoyi tekhniki na osnovi hranychnykh znachen' [Model for testing military equipment based on extreme values]. *Vyprobuvannya ta sertyfikatsiya – Testing and certification*, 2025, no. 1(7), pp. 15-21. DOI: 10.37701/ts.07.2025.02. (In Ukrainian).

19. Tolok, I., Pampukha, I. V., Karpenko, A. O., Tolstanova, G. M., Lushchyk, S. V., Loza, V. M., & Dobrovolsky, V. B. *Avtomatyzovanyy kompleks pryynyattya rishen' pro hotovnist' do zastosuvannya tekhnolohiy i zrazkiv vyznachennya vyhotovlennya ozbroyennya ta viys'kovoyi tekhniki* [Automated decision-making complex for determining the readiness for application of technologies and samples for the production of weapons and military equipment]. Patent for utility model, no. 146818, 2021. Available at: <http://repositsc.nuczu.edu.ua/handle/123456789/22162> (accessed November 19, 2025).

20. Balushok, K. Dosvid stvorenniya ta vprovadzhennya intehrovanoyi systemy tekhnolohichnoyi pidhotovky vyrobnytstva novykh aviatsiynykh dyuhuniv [Experience of designing and implementing integrated system of technological preparation of production for

manufacturing new aircraft engines]. *Mechanics and Advanced Technologies*, 2023, no. 1(97), pp. 24-35. DOI: 10.20535/2521-1943.2023.7.1.278104. (In Ukrainian).

21. Topal, A. V., Sergienko, O. A., & Vysloukh, S. P. Vyrishennya zadach tekhnolohichnoyi pidgotovky vyrobnytstva shtuchnykh neyronnykh mrezh [Solving problems of technological preparation of production by means of artificial neural networks]. *Visnyk Chernihivs'koho derzhavnogo tekhnolohichnoho universytetu. Seriya : Tekhnichni nauky – Bulletin of the Chernihiv State Technological University. Series: Technical Sciences*, 2015, no. 2, pp. 171-175. Available at: http://nbuv.gov.ua/UJRN/Vcndtn_2015_2_30 (accessed November 21, 2025). (In Ukrainian).

22. Pronchakov, Yu. Modelyuvannya rozdashuvannya virtual'noho rozpodilenoho vyrobnytstva v umovakh obmezhenykh mozhyvostey rozvytku pidpryyemstva [Simulation of virtual distributed production location under conditions of limited possibilities of enterprise development]. *Visnyk Natsional'noho tekhnichnoho universytetu "KHPI". Ser.: Systemnyy analiz, upravlinnya ta informatsiyni tekhnolohiyi – Bulletin of the National Technical University "KhPI". Series: System Analysis, Control and Information Technologies*, 2021, no. 1(5), pp. 47-51. DOI: 10.20998/2079-0023.2021.01.07. (In Ukrainian).

23. Li, C., Chang, Q., Xiao, G. & Arinez, J. Integrated Process-System Modeling and Performance Analysis for Serial Production Lines, *IEEE Robotics and Automation Letters*, July 2022, vol. 7, no. 3, pp. 7431-7438. DOI: 10.1109/LRA.2022.3181741.

24. Fedorovych, O., Slomchynskiy, O., Yelizieva, A., Smidovych, L., & Yashina, E. Modeli doslidzhennya stiykosti vysokotekhnolohichnykh vyrobnytstv v suchasnykh polityko-ekonomichnykh umovakh [Models for studying the stability of high-tech productions in modern political and economic conditions]. *Aviatsiyno-kosmichna tekhnika i tekhnolohiya – Aerospace Technic and Technology*, 2023, no. 4, pp. 92-100. DOI: 10.32620/aktt.2023.4.12. (In Ukrainian).

25. Mavrenkov, O., Kubar, S., & Ulizko, V. Analiz ryzykiv, shcho zabezpechuyut' realizatsiyu proektiv postachannya zrazkiv ozbroynennya ta viys'kovoyi tekhniky v umovakh voyennoho stanu [Analysis of the risks accompanying the implementation of projects for the supply of weapons and military technique samples under the conditions during of war]. *Zbirnyk naukovykh prats' Derzhavnogo naukovy-doslidnoho instytutu aviatsiyi – Collection of scientific works State Research Institute of Aviation*, 2023, no. 19(26), pp. 26-34. DOI: 10.54858/dndia.2023-19-3. (In Ukrainian).

Отримано 04.12.2025, отримано у доопрацьованому вигляді 05.01.2026
Дата ухвалення 15.01.2026, дата публікації 22.01.2026

МОДЕЛЮВАННЯ СКОРОЧЕННЯ ЖИТТЄВОГО ЦИКЛУ ЩОДО ШВИДКОГО СТВОРЕННЯ БПЛА ДЛЯ ВИКОРИСТАННЯ У ВІЙСЬКОВИХ МІСІЯХ

О. Є. Федорович, А. В. Попов, Т. С. Пісклова, Л. В. Малєєв, А. В. Рибка, В. А. Федорович

Сучасна війна змінила представлення щодо стратегії, тактик військових дій, а також використання нових видів техніки., як для оперативно-тактичних дій так і для нових технологій у військовій техніці. Поява БПЛА різноманітного призначення призвело до можливості їх використання не тільки на полі бою, а й в глибокому тилу противника. Але, для створення паритету у військових діях з противником, необхідно забезпечити швидке втілення інновацій у розробку нової техніки, з можливістю масштабування та масованості випуску необхідної кількості озброєння. Тому, **актуальне** проведення дослідження щодо формування нового комплексу проектних дій, які дозволять скоротити життєвий цикл (ЖЦ) створення військової техніки. **Предметом дослідження** в роботі є розробка аналітичних та імітаційної моделей, які дозволять аналізувати та планувати необхідні проектні дії щодо скорочення ЖЦ створення високотехнологічних виробів (БПЛА). **Метою** дослідження є створення комплексу математичних та імітаційної моделей, за допомогою яких можна сформувавши нову архітектуру виробу, оптимізувати основні показники проекту та сформувавши проектні дії щодо скорочення ЖЦ, в умовах обмежених можливостей. **Завдання**, які необхідно вирішити: системно проаналізувати ЖЦ створення високотехнологічного виробу у напрямку його скорочення; створити новий метод формування архітектури виробу, з використанням компонентного підходу; сформувавши паралельні процеси проектних дій, які забезпечать скорочення ЖЦ; оптимізувати час, витрати та ризики проектних робіт, в умовах обмежених можливостей; провести моделювання запропонованих дій щодо скорочення ЖЦ створення високотехнологічного виробу (БПЛА). Використані **математичні методи та моделі**: системний аналіз, для створення послідовності проектних дій, які забезпечують скорочення ЖЦ; модель компонентного представлення архітектури нового виробу; метод вибору раціонального варіанту проектування, з використанням лексикографічного впорядкування варіантів; модель оптимізації часу, витрат, в умовах допустимих ризиків проекту; агентне імітаційне моделювання послідовності проектних дій для забезпечення скорочення

ЖЦ створення нової техніки. Отримані наступні **результати**: запропоноване системне представлення проєктних щодо скорочення ЖЦ; обґрунтована компонентна архітектура нового виробу; проведено адаптування базової архітектури до вимог проєкту створення нової техніки; сформована множина можливих варіантів проєкту створення нової техніки, з вибором раціонального; проведена оптимізація часу, витрат, в умовах допустимих значень проєктних ризиків; проведено імітаційне моделювання послідовності проєктних дій.

Висновки: запропонований підхід дозволяє обґрунтувати проєктні дії щодо скорочення ЖЦ створення нової техніки для подальшого швидкого випуску актуальної продукції, в умовах особливого стану країни. **Новизна** запропонованого підходу полягає у наступному: науковому обґрунтуванні проєктних дій щодо скорочення ЖЦ створення нового виробу, з використанням компонентного підходу та паралельного виконання проєктних дій, що забезпечить швидкість створення військової техніки та дасть можливість щодо масованого випуску актуальної продукції для фронту.

Ключові слова: швидке створення нової техніки; життєвий цикл створення складних виробів; компонентна архітектура; паралельні процеси проєктування; оптимізація часу та витрат; ризики проєктування; обмежені можливості; імітаційне моделювання.

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

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

Пісклова Тетяна Сергіївна – мол. наук. співроб. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна.

Малєєв Леонід Вікторович – асп. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна.

Рибка Андрій Вікторович – асп. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна.

Федорович Валерій Андрійович – асп. каф. комп’ютерних наук та інформаційних технологій, Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна.

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

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

Tetyana Pisklova – Junior Research Fellow at the Department of Computer Science and Information Technologies, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine, e-mail: t.pisklova@khai.edu; ORCID: 0009-0003-5375-0120.

Leonid Malieiev – PhD Student at the Department of Computer Science and Information Technologies, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine, e-mail: kafius@ukr.net, ORCID: 0009-0008-8896-2138.

Andriy Rybka – PhD Student at the Department of Computer Science and Information Technologies, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine, e-mail: kafius@ukr.net.

Valeriy Fedorovich – PhD Student at the Department of Computer Science and Information Technologies Department, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine, e-mail: kafius@ukr.net, ORCID: 0009-0006-8615-7608.