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PROJECT MANAGEMENT OF AERONAUTICAL SYSTEM UPGRADE IN UNCERTAIN CONDITIONS

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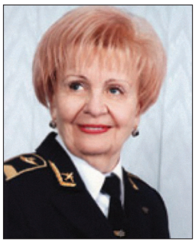

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Abstract. The article researches the project management upgrade of an aeronautical system in conditions of uncertainty. An approach based on artificial immune systems and Bayesian networks is suggested.

Keywords: aeronautical system, immune algorithm, clone immune algorithm, Bayesian trust networks, project management, efficiency, quality and flight safety criteria, decision making and optimisation methods.

1. Introduction

In the modern aviation environment, upgrading aircraft is a field of interest for the majority of countries all over the world, especially considering that aircraft upgrade costs do not exceed 10–20% of the price of a new aircraft. The cost is attractive due to the rapid increase in prices for new aircraft, global recession, and continuous aging of aircraft fleets.

Aircraft upgrade means modernising obsolete and ageing aircraft, improving performance and efficiency by replacing structural elements, and improving materials and manufacturing methods.

The main part of the global passenger and transport aircraft fleet is continuously being upgraded to meet the ICAO requirements. For example, one of the world's largest cargo aircraft, the Antonov 124 designed in Antonov Design Bureau, after upgrade considerably extended its operational performance, eventually meeting the ICAO noise level, navigation accuracy, and safety requirements. Take-off mass and payload of the 124-100M-150 version have been increased to 402 tonnes and 150 tonnes respectively; moreover its performance increased considerably.

Upgrading aircraft upgrade requires the solution of complex problems that are grounds for the estimation of necessity, determination of optimal aircraft upgrade versions, and development of optimal implementation plans.

Realisation of this set of tasks for upgrading aircraft requires the development of methodology and overall methodological provision. Its level directly influences the basis of making decisions regarding the upgrade and efficient growth and implementation costs. This provision includes methods, algorithms and criteria.

2. Problem statement

Methods of upgrading aircraft and aeronautical systems have been researched and scientific and practical results have been obtained (Samkov 2008; Samkov *et al.* 2010, 2008; Zaharchenko *et al.* 2009). Unfortunately, the essential disadvantage of all this research was the insufficient consideration of risk factors caused by the shortage of resources for the realisation of aircraft and aeronautical upgrade.

Consequently, many aircraft upgrade projects and programmes are not realised due to insufficient resources, especially financial shortfalls, which causes operation delays.

Moreover, the complex methods developed for upgrading aircraft focus only on aircraft, neglecting the ground components of the aeronautical system. It is evident that even one out-dated component may substantially decrease or reduce to zero the efficiency growth level of an aeronautical system as a whole.

An aeronautical system is a functionally interdependent entity of both air and ground components: aircraft, ground handling facilities, airfield technical support, and communication and control facilities that provide efficient support for aircraft tasks (Fig. 1).

Everything is done to achieve a high level of safety and to mitigate risks that can grow due to the process of ageing. Safety is the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of the identification of hazards and management of risks to safety (ICAO... 2009). Safety is increasingly viewed as the outcome of the management of certain organisational processes (in particular upgrading procedures) that have the objective of keeping the safety risks of the consequences of hazards in operational contexts under organisational control.

The methodology for the justification and necessity of upgrading an aeronautical system and optimal upgrade versions have been developed, though the methodological aspects of optimal aeronautical system upgrade plans under conditions of uncertainty in the supply of resources have yet to be developed. Two classes of aeronautical system upgrade tasks under the condition of uncertain supply are given in Fig. 2.

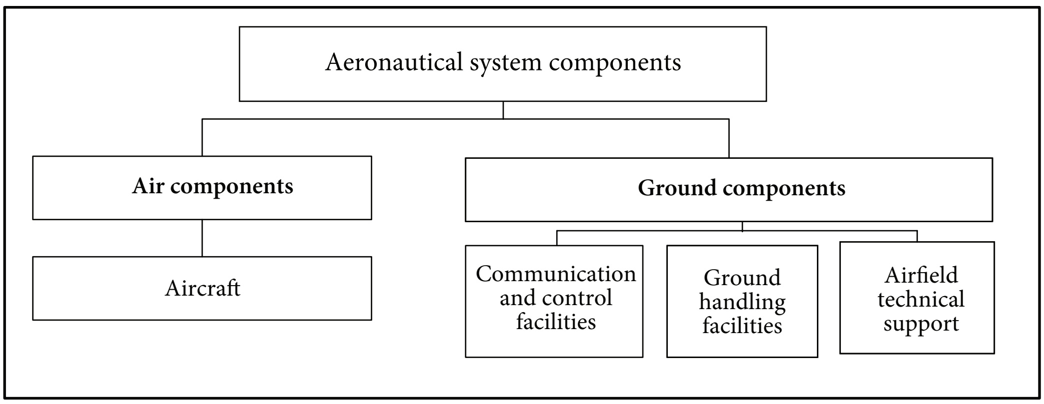

Fig. 1. Aeronautical system components

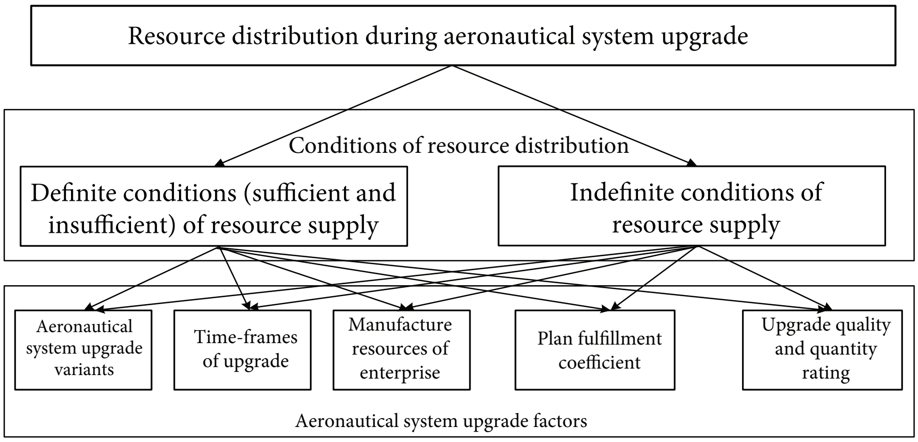

Fig. 2. Two classes of aeronautical system upgrade tasks under the condition of uncertain supply

This task-otherwise referred to as the resource distribution task during aeronautical system upgrade, project management, etc.-is solved under various conditions of material and financial supply in practice. Sufficient and insufficient supply of resources and the receipt of these resources in conditions of uncertainty are possible.

The interconnection between the estimation of optimal aeronautical system upgrade variants and upgrade project management exists. The determination of optimal aeronautical system upgrade variants, required time frames, amount of finances, manufacturing resources, and the main aeronautical system upgrade factors is the important result of solving tasks in various conditions during the planning stage.

At the decision-making stage regarding the aeronautical system upgrade project (determination of financial resources and aeronautical system components that require upgrading), priority is given to the practicability of the project over the synthesis of problems and decisions that can be corrected or limited. For example, due to a financial shortage for an aeronautical system upgrade project, the realisation of the process of aeronautical system upgrade can be adjusted; moreover, less sophisticated and money-consuming variants of aeronautical system upgrade can be elaborated where appropriate.

The management of the modernisation project management and elaboration of an optimal (rational) schedule are the most important tasks of aircraft upgrade. The efficiency levels of the project and its cost depend on the solution of the tasks (Samkov *et al.* 2008). Project management challenges the developers due to the influence of factors of uncertainty during the realisation of the aeronautical system upgrade project.

3. The solution of the problem

The solution of this task is rational resource distribution between all executors during the planning and management of the aircraft upgrade project. Such a solution in conditions of uncertainty allows fulfilling all project and financial requirements.

Method and models of managing aeronautical system upgrade projects based on immune algorithms were suggested for solving such tasks (Samkov *et al.* 2010, 2008; Zaharchenko *et al.* 2009). The use of this method has allowed the number of mistakes at the stage of planning an aeronautical system upgrade to be decreased. It also helps to provide better reasoning for practical recommendations under the condition of resource uncertainty.

Due to the presence of uncertainty in managing aeronautical system upgrades, the stochastic problem statement of the scientific research is considered. It consists of defining the i optimal upgrade variant for a certain type of aeronautical system, assuring the maximum mathematical expectation: a rise in the coefficient of the target function of the aeronautical system after the upgrade and in the presence of uncertainty in scales and terms of finance, taking into account the time limits and upgrade budget (Samkov *et al.* 2008).

Because the task of planning and optimisation during project management is the N-p difficult task of discrete optimisation, the suggestion is made to solve the following task with the help of the heuristic method on the basis of a clone immune algorithm (Doyen *et al.* 2003; Mori *et al.* 1994).

The clonal algorithm is suggested as an optimised universal procedure and allows results close to optimal to be obtained (De Castro, Timmis 2002). It is time saving due to the combination of random and directed search components. Moreover, the clonal algorithm method does not impose limitations such as continuity of objective function, mandatory integrality or validity, unimodality, or smoothness of the surface. In addition, the use of the optimisation algorithm when applying the clonal algorithm is possible and it does not require a numeric expression of the quality of the individual solution while solving the task. This advantage, as well as easiness of implementation, makes the clonal algorithm the best optimisation algorithm for upgrading aeronautical systems in conditions of uncertain and insufficient resources.

On the basis reasoning from artificial immune systems, the task is given as follow (Hart, Ross 1999; Bidiuk *et al.* 2007; Litvinenko *et al.* 2003):

$CLONALG = (P^l, G^k, l, k, m_{Ab}, \delta, f, I, \tau, AG, AB, S, C, M, n, d)$,

where P^l is the space of pool (the space of forms); G^k – search space; l – attribute vector length (dimensions of the search space); k – antibody receptor length; m_{Ab} – size of antibodies population; δ – expression function; f – affinity function; I – antibody population initial preset function; τ – algorithm completion condition; A^G – antigen subset; A^B – antibody population; S – selection operator; C – cloning operator; M – mutation operator; n – number of the best antibodies that are selected for cloning; d – number of the worst antibodies that should be replaced with new ones.

The function $\delta : P^l \to G^k$ is a conversion function of variants for solutions P^l to their internal spaces (G^k) in the form of individuals of population (expression function). It is assumed that for every solution $p \in P^l$ there is only one expression $\delta(p) \in G^k$. Taking into account a generalised view, one can have an affinity function*f*: $f : P^l \times P^l \to \Re^+$. The task is to maximise the affinity function. Taking the initial antibody population size (m_{Ab}), one can consider an initialisation function as $I : G^k \times m_{Ab} \to AB\left(G^k\right)$. We introduce stochastic transformation operator Q of the set G^k, which manages K_Q to generate the control parameters that determine the transformation image on the current stage of the algorithm.

Functional entry operator Q can be expressed as follows: $Q : G^k \times K_Q \to G^k$. The optimal solution $Ab_{opt} \in G^k$ with respect to the operator Q and the antigen $Ag \in AG,\ AG \subset G^k$ is an individual, the affinity of which cannot be increased with further effects of transformation operator Q, that is $\forall k \in K_G : f\left(Q(Ab_{opt}, k), Ag\right) \le f\left(Ab_{opt}, Ag\right)$.

Algorithm completion condition (τ): the antibody population fully recognises the antigen population, that is $\forall Ag \in AG : \exists Ab \in G^k \mid Ab = Ab_{opt}$. Selection operator S forms a subset of individuals G_S, the affinity of which is the best in this generation. Thus, S, together with control set K_S defines this function: $S : G^k \times K_S \to \{0,1\}$. As a result of selection, a set is formed: $G_S = \left\{Ab \in G^k \mid S(Ab, k_S) = 1\right\},\ \ |G_S| = n$.

The cloning operator C increases the set of elements G_S of a population, and together with K_C the control set can be expressed as ... Mutation operator M with control set K_M is given as $M : G^k \times K_M \to G^k$. The meta-dynamic system is expressed as a function of substitution of the worst population of antibodies: $R : G^k \times d \to AB_d\left(G^k\right)$.

The transformation process model of the states of the antibody population by means of the cloning procedure is determined as follows:

$$AB_t \xrightarrow{\text{Selection } (S)} G_S \xrightarrow{\text{Cloning } (C)} G_C \xrightarrow{\text{Hypermutation } (M)}$$
$$G_M \xrightarrow{\text{Re-selection } (S)} G_S \xrightarrow{\text{Replacement } (d)} AB_{t+1},$$

where t – a generation number; AB – a population of antibodies (detectors); G_S – a subset of the best antibodies selected for cloning; G_C – a subset of the clones G_M – a subset of clones after mutations; and d – number of the worst antibodies that should be replaced with new ones (meta-dynamics)

Step by step the implementation of the algorithm is shown below.

Step 1. Initialisation. Generate initial population of antibodies **Ab°**.

$$\mathrm{Ab}^\circ = \varnothing, j \in \{1..N\}, t = 0.$$

Randomly select $\boldsymbol{i}_j \in \mathrm{I}$.

$$\mathrm{Ab}^\circ = \mathrm{Ab}^\circ + \boldsymbol{i}_j,$$

where **I** – the space of individuals, i.e. set of all possible structures of an antibody; $\boldsymbol{i} \in \mathrm{I}$ – a subset of individuals that form the population; and **t** – number of a generation.

Step 2. Determination of affinity. Calculate the value of the objective function $y_j = \boldsymbol{f}(\boldsymbol{Ab}_j)$ and to determine affinity $g_j = affinity(y_j),\ j \in \{1..N\}$ for each antibody $\boldsymbol{Ab}_j \in \mathbf{Ab}^t$.

Step 3. Selection. Select a subset of antibodies with the highest affinity ($\mathrm{Ab}_{\{n\}}$).

$$\mathrm{Ab}_{\{n\}} = \left\{\boldsymbol{Ab}_j \in \mathrm{Ab}^t \mid select(\boldsymbol{Ab}_j, \mathrm{Ab}^t, n) = 1\right\},\ \text{where}$$

$$select(\boldsymbol{Ab}_j, \mathrm{Ab}^t, n) = \begin{cases} 1, rank(\boldsymbol{Ab}_j) < n; \\ 0, rank(\boldsymbol{Ab}_j) \ge n; \end{cases}$$

$$rank(\boldsymbol{Ab}_j) = j,\ if\ \forall j \in \{1..N-1\}:$$

$$affinity(\mathrm{f}(\boldsymbol{Ab}_j)) \ge affinity(\mathrm{f}(\boldsymbol{Ab}_{j+1})).$$

Step 4. Cloning. Obtain a population of clones $\mathrm{C}_{\{N_C\}}$ from $\mathrm{Ab}_{\{n\}}$.

$$\mathrm{C}_{\{N_C\}} = \varnothing,$$

$$\forall j \in \{1..N_C\} : \boldsymbol{C}_j = \boldsymbol{Ab}_k, \boldsymbol{Ab}_k \in \mathrm{Ab}_{\{n\}},\ \text{where}$$

$$k = round\left(\frac{j}{round(\beta \cdot N)}\right),$$

$$N_C = \sum_{i=1}^{n} round(\beta \cdot N),$$

$round(x)$ – the operator of taking the integer part of.

Step 5. Hypermutation. Obtaining modified clone population $\mathrm{C}^*_{\{N_C\}}$ from $\mathrm{C}_{\{N_c\}}$.

$$C^*_{\{N_C\}} = \varnothing;$$

$$\forall j \in \{1..N_C\}: \boldsymbol{C}^*_j = \begin{cases} mutate(\boldsymbol{C}_j), rnd(p_m) = 1; \\ \boldsymbol{C}_j, rnd(p_m) = 0; \end{cases}$$

$$\boldsymbol{C}_j \in C_{\{N_C\}},$$

where $rnd(p_m)$ – the function of modelling the onset of a random event with a given probability p_m and $mutate(\boldsymbol{C}_j)$ – the cloning operator that randomly alters one or more genes of the antibody.

Step 6. Determination of the affinity of modified clone populations. Calculate the value of the objective function $y_j = f(\boldsymbol{C}^*_j)$ and to determine the affinity $g_j = affinity(y_j), j \in \{1..N_C\}$ for each antibody $\boldsymbol{C}^*_j \in C^*_{\{N_C\}}$.

Step 7. Selection. Select a subset $C^*_{\{n\}}$ of the **n** antibodies with the highest affinity from a population of modified clones $C^*_{\{N_C\}}$, like step 3.

Step 8. Replacement. Replace subset $\mathrm{Ab}_{\{n\}}$ by $C^*_{\{n\}}$.

$$\forall j \in \{1..n\}: \boldsymbol{Ab}_j = \boldsymbol{C}^*_j, \quad \boldsymbol{Ab}_j \in \mathrm{Ab}_{\{n\}}, \boldsymbol{C}^*_j \in \boldsymbol{C}^*_{\{n\}}.$$

Step 9. Clonal deletion. Replace a subset of antibodies $\mathrm{Ab}_{\{d\}}$ with new individuals of the lowest affinity.

$$\mathrm{Ab}_{\{d\}} = \left\{ \boldsymbol{Ab}_j \in \mathrm{Ab}^t \mid negselect(\boldsymbol{Ab}_j, \mathrm{Ab}^t, d) = 1 \right\},$$

where

$$negselect(\boldsymbol{Ab}_j, \mathrm{Ab}^t, d) = \begin{cases} 1, rank(\boldsymbol{Ab}_j) \geq N - d; \\ 0, rank(\boldsymbol{Ab}_j) < N - d; \end{cases}$$

$$rank(\boldsymbol{Ab}_j) = j, \ if \ \forall j \in \{1..N-1\}:$$

$$affinity(f(\boldsymbol{Ab}_j)) \geq affinity(f(\boldsymbol{Ab}_{j+1})),$$

$$k \in \{1..d\},$$

randomly choose $\boldsymbol{i}_k \in \mathrm{I}$,

$$\boldsymbol{Ab}_k = \boldsymbol{i}_k, \boldsymbol{Ab}_k \in \mathrm{Ab}_{\{d\}}.$$

Step 10. Break conditions check. Check the condition ε; stop the algorithm on the selected criteria.

$$\mathrm{Ab}^{t+1} = \mathrm{Ab}_{\{n\}} \cup \mathrm{Ab}_{\{d\}} \cup \mathrm{Ab}_{\{N-(n+d)\}},$$

$$t = t + 1,$$

Conclusion, $\mathrm{Ab}_{\{n\}}$, *if* $stop(\varepsilon) = true$,

Return to Step 2, *if* $stop(\varepsilon) = false$.

Commentary. A mutation operator is not considered in detail in this work because today there are many different options for its implementation.

n and *d* parameters are not connected with each other directly, but only via population size N, i.e. restrictions are imposed on them – $n + d \leq N$.

This means that individuals after one generation can remain unmodified in the population.

Before the operator selection is applied, all individuals should be ranked, i.e. it is necessary to sort the population in the affinity decreasing sequence.

As a result, the lowest rank will be given to an individual with the highest affinity.

The defined issues to build the clonal immune algorithm are the form of task decision presentation as antibodies (individuals), the affinity function, and the reproduction procedure, which includes the operators that select, clone and mutate antibodies (De Castro, Timmis 2002; Doyen *et al.* 2003).

One of the most practical decisions of the tasks analysed is the three-dimensional matrix, the axes of which are respectively the following: types of aircraft systems, divided in accordance with the production capacity to carry out the upgrade; the variants of each type of aircraft system upgrade; the work to be performed to carry out the upgrade.

To carry out the clonal selection in the process of the development of the upgrade plan, the entire list of works on aeronautical system upgrade, as well as their resource limitations, is formalised as antibodies. This type of formalisation represents the sequence of the planned tasks with markings of task fulfilment or nonfulfilment at a certain stage of the upgrade. The general view of clonal immune algorithm of the task fulfilment schedule of the aeronautical system upgrade is suggested in Fig. 3.

The resulting schedule is elaborated on the basis of the evaluation of task lists by the method of

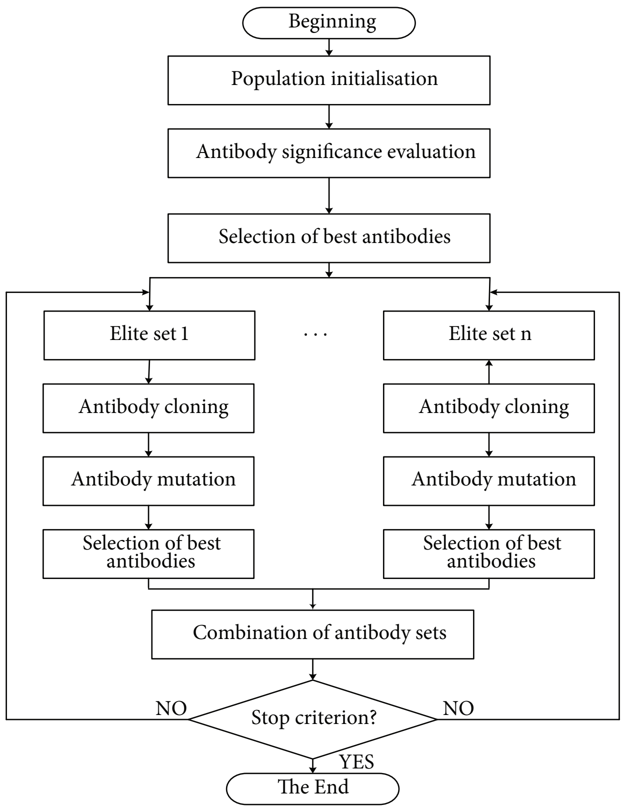

Fig. 3. General view of the clonal immune algorithm for the task fulfilment calendar of aeronautical system upgrade

incomplete enumeration. The significant criterion of such formalisation is the compliance with the requirement of ensuring the uniqueness of all antibody genes, that is their inclusion into each calendar task or resource only once during the process of all scheduled fulfilment of tasks during the aeronautical system upgrade.

However, the use of this algorithm does not consider hazards, inaccuracy of original data, etc., which allows only partly solving the challenges of uncertainty in the process of managing aeronautical system upgrade tasks. Thus, in order to solve the assigned task, the suggestion is made to additionally apply the apparatus based on the Bayes nets of trust and to develop the hybrid approach based on the combination of the Bayes nets and artificial immune systems, where the latter play the role of an efficient computing tool for sorting out task solution (Heckerman 1995).

Bayes nets of trust are one of the most popular methods of presenting knowledge with uncertainty (Heckerman 1995). In general terms, Bayes nets of trust are a directed graph that does not contain any directed cycles but consists of nodes and arcs. Nodes represent random variables that can be discrete or continuous. Arcs represent the cause-and-effect relations between the variables; Bayes nets of trust are therefore sometimes called cause-and-effect nets. The principal purpose of the Bayes nets of trust is to get information about variables inaccessible to observation via the information that comes into the observable variables and the connections between them.

Probable distributions for all net variables while managing the upgrade project can be defined on the basis of the use of the Bayes theorem together with the two principles of probability calculation. The basic benefits of Bayes nets of trust application versus common mathematical models are an intuitively intelligible and reasonable presentation of interconnections of arguments, variable existence possibility both by way of the argument and the required object in the scope of one structure, and an information dissemination chance in both directions of the Bayes nets (Heckerman 1995).

Application of the appliance on the basis of the Bayes nets of trust allowed developing a model for upgrading the aeronautical system, taking into consideration the uncertainties and input data, which consists of information concerning the upgrade resources together with an evaluation of the need for such resources.

During the next stage on the basis of the immune algorithms, the optimal resource allocation task is solved for aeronautical system upgrade task fulfilment, calendar task set is formed, out of which the best one is chosen. Calendar aeronautical system upgrade task formation algorithm in the framework of the uncertainty on the basis of hybrid approach can be seen in Fig. 4.

4. Modelling results

Thereby, on the basis of the formalisation and solution of research tasks, the following is developed: a conceptual approach to aeronautical system upgrade tasks and a structural-functional model of project management for upgrading aeronautical systems on the basis of artificial immune net algorithms and Bayes nets of trust (Fig. 4). The use of the suggested model allows a schedule for aeronautical system upgrade tasks to be prepared after considering all aforementioned criteria and limitations.

Fig. 5 shows the rate of algorithm convergence dependent upon the number of the initial population, modified immune algorithm iteration step (X axis), and time necessary to reach the optimal decision for task planning (Y axis). Analysis of the diagram reveals the nearest convergence under the population number higher than 100 persons (plan alternatives). The most optimal time alternative also requires the initial populations to consist of 100 and more antibodies.

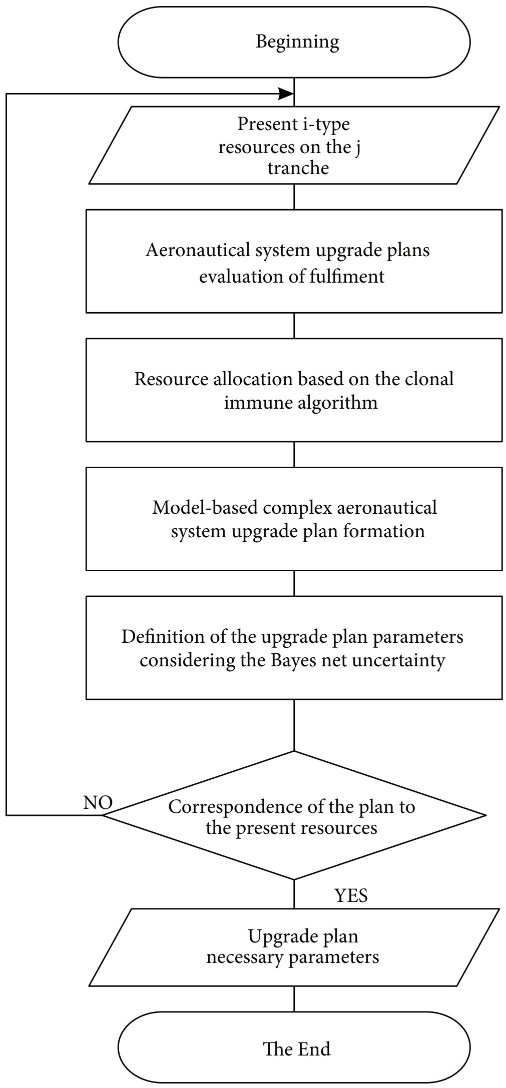

Fig. 4. Hybrid approach algorithm for formation of aeronautical system plan in uncertain conditions

For comparative evaluation of different algorithms while preparing the schedule for aeronautical system upgrade tasks, assessment of their convergence rate is carried out. Three algorithms are compared: simple immune algorithm of clonal selection, genetic algorithm, and modified immune algorithm for the determination of the schedule for aeronautical system upgrade tasks.

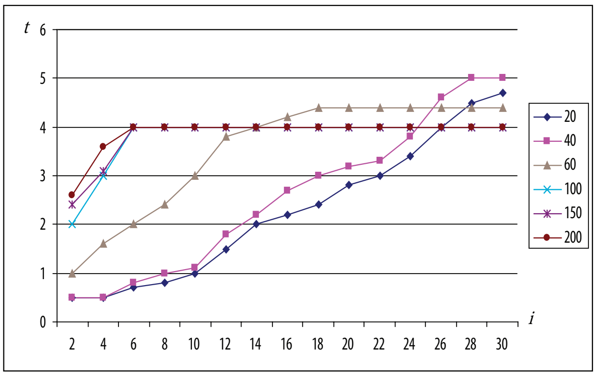

Fig. 5. Dependence of algorithm convergence rate on initial population number

By analysing the results (Fig. 6) we came to the conclusion that the highest rate of coincidence is established between immune algorithm and modified immune algorithm.

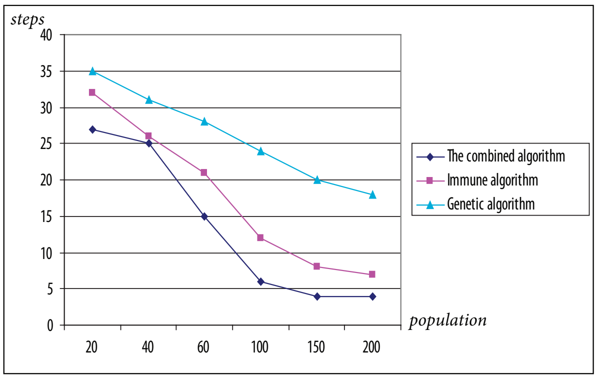

Fig. 6. Convergence rate of various algorithms

5. Conclusion

Thus, a model for an aeronautical system upgrade plan was developed and methods based on the hybrid approach for combined application of artificial immune systems and Bayesian networks were suggested. The use of these methods allows upgrade project management tasks to be solved in conditions of uncertainty.

Moreover, the practical implementation of this approach provides the opportunity to receive reliable planning results based on upgrade plans when there is uncertainty about resources and it minimises resource waste.

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AERONAUTIKOS SISTEMŲ ATNAUJINIMO PROJEKTŲ VALDYMAS NEPASTOVIOMIS SĄLYGOMIS

A. Samkov, G. Suslova, V. Litvinenko, Y. Zacharčenko

Santrauka. Straipsnyje tiriamas aeronautikos sistemų atnaujinimo projektų valdymas nepastoviomis sąlygomis. Siūloma naudoti dirbtines atsparias sistemas ir Bajeso tinklus.

Reikšminiai žodžiai: aeronautikos sistema, atsparus algoritmas, klonavimui atsparus algoritmas, saugūs Bajeso tinklai, projektų valdymas, efektyvumo, kokybiniai ir skrydžių saugos kriterijai, sprendimų priėmimo ir optimizacijos metodai.