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SELECTING A MODEL OF UNMANNED AERIAL VEHICLE TO ACCEPT IT FOR MILITARY PURPOSES WITH REGARD TO EXPERT DATA

Проведена порівняльна характеристика багатокритеріальних задач оптимізації, критерії яких можуть мати кількісну і якісну природу. Обґрунтовано рішення щодо вибору зразка безпілотного літального апарату для прийняття на озброєння за характеристиками, значення яких прогнозуються в умовах нестохастичної невизначеності на основі експертних даних. Запропонована декомпозиція проблеми в ієрархію, що відображає зміст багатокритеріальної задачі оптимізації

Ключові слова: безпілотний літальний апарат, декомпозиція проблеми в ієрархію, лінгвістична змінна

Проведена сравнительная характеристика многокритериальных задач оптимизации, критерии которых могут быть количественной и качественной природы. Обоснованно решение относительно выбора образца беспилотного летательного аппарата для принятия на вооружение с характеристиками, значения которых прогнозируются в условиях нестохастической неопределенности на основе экспертных данных. Предложена декомпозиция проблемы в иерархию, которая отражает содержание многокритериальной задачи оптимизации

Ключевые слова: беспилотный летательный аппарат, декомпозиция проблемы в иерархию, лингвистическая переменная

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1. Introduction

Defensive military doctrine of the Armed Forces of Ukraine (AFU) establishes high requirements for all elements of combat readiness and for training troops. The Armed Forces must be prepared to fight off aggression by conducting defensive actions. The most important task of the headquarters under defensive nature of the military doctrine is permanent surveillance of the enemy that should provide for a timely and organized transition of troops from peace to war. The main role in this is assigned to the intelligence. A number of tasks for aerial reconnaissance can be solved under conditions of strong air defense capabilities from the enemy with the use of unmanned aerial vehicles (UAV) [1, 2]. An analysis of experience of using UAV in modern military conflicts allows us to conclude that the main combat tasks for UAV during wars in North Vietnam, Yugoslavia, Chechnya, Afghanistan, and Syria were solving the tasks of intelligence and observation of the battlefield [3, 4].

That is why, at present, UAV are considered as an effective and reliable means of aerial reconnaissance. Due to the rapid supply of complete, reliable information about the enemy, combat success is achieved.

In line with the opinions of experts [5–7], in combat, the most promising type of weapons is UAV for military purposes. Combat capabilities of the units of new type with UAV will increase by 2–2.5 times. Currently, 30 countries produce up to 150 types of UAV, with 80 of them employed by 55 armies around the world. The leading countries in this field are the USA, Israel and China. According to specialists, over 2015–2025, a share of the USA in the world spending on UAV will amount to 62 % on research and design work, and to 55 % in purchases [5, 6]. A strategy for developing the Ukrainian aviation industry through 2020 and results of the research potential of enterprises for the future implies increasing the volumes of development and aviation equipment production [8].

The Ukrainian Air Forces today use outdated Soviet operation–tactical and operational unmanned aviation complexes VR-2 "Strizh" and "Reis", which do not meet modern requirements, have limited capabilities, and use them as air targets. The indicated complexes, by their tactical-technical characteristics, are hopelessly behind modern designs of unmanned reconnaissance aircraft in the world and need replacing or complete modernization. Everyday combat practice of conducting military operations against armed groups in the Eastern Ukraine confirms the need for applying new means of armed struggle to enable the activities of the smallest tactical units. Therefore, the Ministry of Defense of Ukraine defined quantitative and qualitative needs of AF in the required classes of UAV and preliminary requirements for them; however, the problem of defining an exactly promising kind of UAV for using by AFU remains relevant. An analysis of open sources in the field of UAV development makes it possible to substantiate the choice of prospective model of UAV for military purposes [4–7, 13].

Determining a UAV model to be armed with includes the enumeration and content of their basic tactical-technical characteristics that constitute its information resource. In the absence of necessary statistics on the values of tactical-technical characteristics (TTC), their quantitative values are to be predicted. Prediction is possible only based on expert data and the inspection may have to deal with a fuzzy statement.

2. Literature review and problem statement

The issue of providing AF with modern UAV and accepting them for arming has been addressed repeatedly and at different levels, but up to now it has remained unresolved. [8] laid a groundwork for the formation and implementation of state policy in the field of development, production, sale and service maintenance of aviation equipment. However, the needs of AFU in UAV have not been clearly identified, as well as approaches regarding the choice of specific models. [9] proposed a method for creating viable strategies in the modernization and production of new armaments and a method for determining performance indicators and decision making risk under conditions of nonstochastic uncertainty, however, the question on the substantiation of selection procedure and acceptance of existing samples for arming was not considered.

Articles [10–12] proposed a method to design and develop UAV by engaging a multidisciplinary group of experts in the field of aeronautics, systems management and combat use. However, questions about the formalization of procedures for substantiation the decisions taken by experts remain uncovered by the article and point to a general approach toward solving a task on the choice of requirements when devising UAV. An analysis of the main classes of UAV, used by ground forces to solve a wide range of combat tasks and the possibility of their shared utilization with the units of army aviation, was performed in [13]. However, a procedure for selecting specific types and models of UAV was not considered. There were no results of employing UAV of various types. A current state of the problems in the development of unmanned aerial vehicles, main trends of future development, scientific and industrial potential of Ukraine, which is not used to the fullest, were defined in [14]. Nevertheless, article [14] substantiated all decisions by using statistical data without taking into account the risks and uncertainties of various kinds, which affect the production and development of UAV.

Papers [1, 8, 15] presented basic characteristics for UAV of tactical activity that are in service by the world leading countries. In this case, paper states the fact of availability of particular UAV. The reasons and procedures for their selection are not examined.

However, a set of TTC can provide the experts with basic information to predict the values of main characteristics of a prospective UAV model for AFU. An analysis of arming troops with unmanned aviation confirms expediency of taking into account characteristics of the intelligence UAV Raven RQ-11 made in the USA, when conducting the appraisal. This type of UAV was delivered to the Armed Forces in June 2016, for use in the region of armed conflict in the Eastern Ukraine [16]. It is necessary to take into account as well the tactical-technical specifications of UAV "Furiya" and "Spectator" made in Ukraine, which were purchased by the Ministry of Defense to perform tasks in the area of conducting anti-terrorist operation [14]. The presence of these UAV and the gained experience of their application will make it possible to verify feasibility of the devised method based on existing data and to evaluate its performance efficiency.

Therefore, it appears promising to solve the following task: to define a model of UAV for accepting it in service by AFU by the predicted values of basic tactical-technical characteristics in the form of a fuzzy statement.

3. The aim and tasks of the study

The aim of present work is to substantiate a decision on selecting the model of UAV for military aviation service by the accepted indicators.

To achieve the set aim, the following tasks were to be solved:

– to conduct a comparative evaluation of multi-criteria optimization problems whose criteria may match the factors that reflect both the quantitative and the qualitative attribute;

– to predict values of TTC of UAV models under conditions of nonstochastic uncertainty based on setting the appraisal and processing of expert data;

– to substantiate a decision regarding the UAV model by the accepted indicators taking into account the priority vector of basic characteristics.

4. Methods for selecting a UAV model with regard to the predicted values of basic tactical-technical characteristics

A comparative evaluation of several samples of UAV is related to the statement and solution of multi-criteria optimization problem. The known methods to solve multi-criteria optimization problems are the formation of generalized criterion, selection of basic criterion, hierarchy analysis.

A method for selecting the basic criterion implies that a multi-criteria original problem is reduced to a single-criteria optimization problem. The formation of the problem is carried out after obtaining an answer to the problem on criteria ranking and defining the constraints for criteria. A method for the formulation of generalized criterion is limited in its application by the fact that, when considering applied problems on compiling a generalized criterion, it causes the difficulties that are difficult to overcome. The method of successive concessions also requires first and foremost solving a problem of criteria ranking and bringing their measurement to one scale, determining the magnitudes of concessions for each criterion. A method of hierarchy analysis, which is considered in [17, 18], in terms of its application for solving multi-criteria optimization problems of different physical nature, has no disadvantages or "nuisances". Moreover, the criteria can match the factors that reflect both the quantitative and qualitative attribute [19].

According to [7], main UAV TTC include:

– flight duration;
– flight speed;
– flight altitude;
– activity range;
– cost of manufacturing;
– demand in the market of armaments;
– competitiveness.

When considering prospective UAV designs, their basic above-mentioned TTC will take predicted values. We note that if a researcher has statistics, for example, on the values of activity range while observing the battlefield, then the task on predicting the value of this characteristic can be stated and solved under conditions of stochastic uncertainty. Smoothing stochastic values in time

$$t_i<t_0,\ i=\overline{1,n}, \tag{1}$$

where t_0 is the time of decision making, can be performed by the least squares method under assumption of accepted functional dependence of the TTC values on time. Then the problem on predicting for the time $t=t_0+\tau$ is in the fact that the resulting smoothing of TTC values is extrapolated. Such determining of predictive values implies the assumptions that the set of factors, which defined the TTC statistical values, remains unchanged over the predicted time duration τ. Under this assumption, the long-term prediction of TTC values cannot be regarded as satisfactory. If a researcher does not have statistics or if it is limited, then the prediction of TTC values for UAV samples should be considered under conditions of nonstochastic uncertainty.

Under conditions of nonstochastic uncertainty, the prediction of UAV TTC values is possible only based on setting the appraisal and processing expert data. In the appraisal setting, a problem on decision-making is solved

$$<\Omega_l,\ OP_l>, \tag{2}$$

where Ω_l is the set of estimates of TTC values by expert, and OP_l is the optimality principle of expert. A researcher may propose such a procedure for appraisal, in which each ℓ-th expert expresses own subjective opinion relative to the predicted value of the UAV TTC sample by a clear statement of three grades: pessimistic, the most expected and optimistic. Further build-up of credibility to the subjective evaluations of experts might involve fuzzy assessment of the predicted TTC values when each expert expresses own opinion regarding the predicted value in the form of a fuzzy triangular number.

Fuzzy number $\tilde{A}$ in the actual line is a fuzzy subset, which is characterized by a membership function $\mu\tilde{A}(x)$: $R\rightarrow[0,1]$. Fuzzy number $\tilde{A}$ is represented in the form:

$$\tilde{A}=\int\left(\mu_{\tilde{A}}(x)/x\right), \tag{3}$$

where $\mu\tilde{A}(x)\in[0,1]$ is the degree of membership of $x\in R$ to subset $\tilde{A}$, $\int$ is the symbol of unification by all $x\in R$.

Then the prediction of value of k-th TTC of UAV model is described by a fuzzy triangular number (fuzzy subset) whose membership function is presented in Fig. 1 and takes the form:

$$\mu_{\tilde{C}_k}(x)= \\ =\begin{cases}\left(x-(C_k-\delta_1)\right)/\delta_1 & \text{at } C_k-\delta_1\le x\le C_k;\\ \left((C_k+\delta_2)-x\right)/\delta_2 & \text{at } C_k\le x\le C_k+\delta_2;\\ 0 & \text{at } 0\le x\le C_k-\delta_1, x\ge C_k+\delta_2.\end{cases} \tag{4}$$

The procedure of appraisal implies that every l-st expert expresses own subjective opinion in the form of three values relative to the C_k-th TTC of UAV model, namely:

– $\left(C_k^{(l)}+\delta_1^{(l)}\right)$ is the pessimistic assessment;
– $C_k^{(l)}$ is the most expected assessment;
– $\left(C_k^{(l)}+\delta_2^{(l)}\right)$ is the optimistic assessment.

Then these assessments are averaged accordingly given the weight coefficients of experts and maintain the description of the first TTC in the form (4).

If we accept $\mu_{\tilde{C}_k}(x)=\alpha$, then the clear α-level subsets are determined:

$$\left\{C_k^{\alpha}=\overline{C}_k^{\alpha},\dots,\overline{\overline{C}}_k^{\alpha}\right\}, \tag{5}$$

where $\overline{C}_k^{\alpha}$, $\overline{\overline{C}}_k^{\alpha}$ are the left and right boundaries of value of the C_k-th TTC model of UAV, respectively. Based on the content of the fuzzy subset $\tilde{C}_k$, the researcher accepts $\alpha\geq\alpha_{r.c.}$ as the level of required confidence in the predicted values of the C_k-th TTC, for example, $\alpha_{r.c.}$ can be determined as $\alpha_{r.c.}=0{,}5$.

For the purpose to determine, by the predicted values of basic TTC in a fuzzy statement, for promising armament models on the example of UAV, we shall consider the following possible decomposition of the problem into a hierarchy, which is shown in Fig. 2.

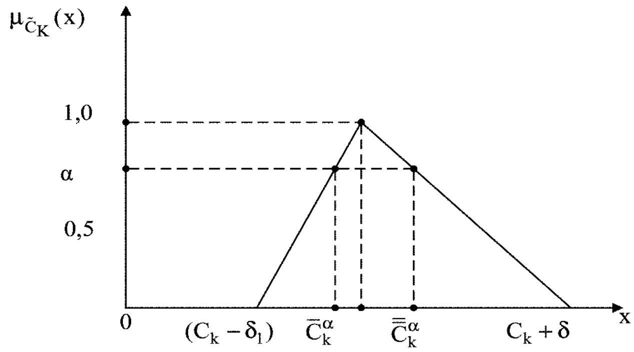

Fig. 1. Description of the UAV TTC sample value by a fuzzy triangular number

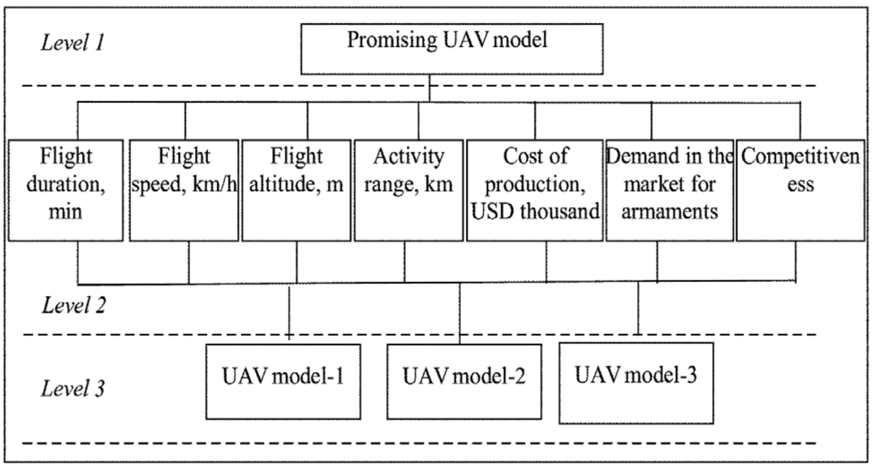

Fig. 2. Decomposition of problem into hierarchy

As shown in Fig. 2, the decomposition of problem into a hierarchy has three levels:

– level 1 corresponds to the goal, which is achieved by solving the problem;

– level 2 includes indicators (criteria), by which one or another alternative for a promising model of UAV should be accepted;

– level 3 corresponds to the list of source data, which in the opinion of decision maker comprises their full set.

Thus, the decomposition of problem in hierarchy represents the contents of the multicriteria optimization problem, which has a peculiarity:

– a fuzzy description of predicted values C_k of basic UAV TTC (indicators C_1, C_2, C_3, C_4), which have a clearly defined numerical nature and are measured in appropriate magnitudes;

– a fuzzy predicted description of the indicator "cost of UAV model production" (C5), which can be assigned to quantitative nature and to qualitative nature;

– a fuzzy predicted description of the indicators "demand in the market for armaments", "competitiveness", which have a clearly expressed qualitative nature. It was noted above that the indicators that have quantitative nature should be predicted in a fuzzy statement, and fuzzy triangular numbers should describe their predicted values. The indicators that have a qualitative nature should be predicted based on the introduction of appropriate linguistic variables for consideration.

According to [17], a linguistic variable is understood as tuple

$$<\beta, T(\beta), G, M>, \tag{6}$$

where β is the name of linguistic variable; G is the syntactic rule that generates the name of fuzzy variable $\gamma \in T(\beta)$ as verbal meanings of linguistic variable; M is the syntactic rule that assigns fuzzy subset $\tilde{C}(\gamma)$; to each fuzzy variable $\gamma \in T(\beta)$; $T(\beta)$ is the term-set of linguistic variable whose elements γ_i are the name of the fuzzy variable as linguistic values of linguistic variable

$$<\gamma, X, \tilde{C}(\gamma)>, \tag{7}$$

where X is the region of determining fuzzy variable; $\tilde{C}(\gamma)$ is the value of membership function of fuzzy subset

$$\tilde{C}(\gamma)=\left\{\mu_{\tilde{C}(\gamma)}(x)/x\right\},\ \ x\in X,\ \ \mu_{\tilde{C}(\gamma)}(x). \tag{8}$$

Relative to the fuzzy indicator "demand in the market for armaments", we can define linguistic variable β_n – "necessity", and the term–set $T(\beta_n)$ can be determined by two fuzzy variables: $\gamma_{n,1}$ – "low demand" and $\gamma_{n,2}$ – "high demand". Relative to the fuzzy qualitative indicator "competitiveness", we can defined linguistic variable β_c –"competitiveness" and the term-set $T(\beta_c)$ can be determined by three fuzzy variables: $\gamma_{c,1}$ – "acceptable competitiveness", $\gamma_{c,2}$ – "significant competitiveness", $\gamma_{c,3}$ – "high competitiveness". Determining the membership functions of fuzzy variables $\gamma_{n,1}$, $\gamma_{n,2}$ of linguistic variable β_n and fuzzy variables $\gamma_{c,1}$, $\gamma_{c,2}$, $\gamma_{c,3}$ of linguistic variable β_c is carried out by setting the appraisal and processing expert data. Each l-th expert,

$$\ell=\overline{1,L}, \tag{9}$$

expresses own subjective opinion about this: by how many times the value of membership function:

$$\mu_{\tilde{C}(\gamma_{n,1})}(x_i), \tag{10}$$

for example, one considers a fuzzy subset $\tilde{C}$ $(\gamma_{n,1})$ of fuzzy variable $\gamma_{n,1}$, exceeds the value of membership function:

$$\mu_{\tilde{C}(\gamma_{n,1})}(x_j), \tag{11}$$

where x_i, $x_j \in X$; $i,j=\overline{1,n}$, X is the determining domain of linguistic variable β_n. Such opinion is submitted by expert, based on the qualitative assessment scale, which is specified in [17].

Experts submit binary comparisons $\mu_{\tilde{C}(\gamma_{n,1})}(x_i)$ and $\mu_{\tilde{C}(\gamma_{n,1})}(x_j)$ by such scale in the form of matrix:

$$A(\ell)=\left\|a_{ij}(\ell)\right\|,\ \ell=\overline{1,L};\quad i,j=\overline{1,n}. \tag{12}$$

Then matrices $A(\ell)$ are averaged and the matrix decomposes:

$$A=\left\|a_{ij}\right\|,\ \ i,j=\overline{1,n}. \tag{13}$$

Matrix equation corresponds to each square A

$$AY^T=\lambda Y, \tag{14}$$

which makes it possible to define its corresponding integers:

$$\lambda_q, \quad q=\overline{1,G}, \tag{15}$$

as roots of characteristic equation:

$$A-\lambda E=0, \tag{16}$$

where E is the identity matrix. Eigenvectors Y_q complies with each town number λ_q. If we have for matrix A:

$$a_{ij}>0;\ a_{ji}=1/a_{ij};\ a_{iк}=a_{ij}\cdot a_{jк};$$

$$i,j,k=\overline{1,n}, \tag{17}$$

that is, matrix A is integral, inversely symmetrical and coordinated, then equation:

$$A-\lambda E=0, \tag{18}$$

have one root:

$$\lambda=\lambda_{max}=n. \tag{19}$$

It is matched with only one own vector Y. Thus, if the subjective judgments of experts regarding:

$$\tilde{C}(\gamma_i)=\left\{\mu_{\tilde{C}(\gamma_i)}(x)/x\right\},\ x\in X,\ i=\overline{1,5}, \tag{20}$$

for $\gamma_{n,1}$, $\gamma_{n,2}$; $\gamma_{c,1}$, $\gamma_{c,2}$, $\gamma_{c,3}$, will be represented by integral, inversely symmetrical and coordinated matrix, then the solution for equation $AY^T=nY$ allows us to define a vector:

$$Y=\left\{\mu_{\tilde{c}(\gamma\ )}(x)\right\}, \tag{21}$$

and numerical measure of divergence λ_{max} and n will determine a numerical measure of coherence in the judgments of experts. Each l-th expert, using a qualitative scale, which is specified in [17], expresses own opinion relative to the membership function:

$$\mu_{\tilde{C}(\gamma)}(x_j);\quad i,j=\overline{1...n};\ x_i,x_j\in X. \tag{22}$$

In accordance with $A\mu^T=\lambda_{max}-\mu$, we can form a vector:

$$\mu=\left\{\mu_{\tilde{C}(\gamma)}(x_j)\right\},\ j=\overline{1,n}, \tag{23}$$

because

$$\mu_{\tilde{C}(\gamma)}(x_j)=1/k_j. \tag{24}$$

In a general case, the resulting vector μ might not satisfy equation:

$$AY^T=nY, \tag{25}$$

because the consistency of integral inversely symmetrical matrix meets the requirement $\lambda_{max}\geq n$. Deviation from the consistency is estimated by ratio:

$$\eta=\left(\tilde{\lambda}_{max}-n\right)/\left(n-1\right), \tag{26}$$

because at binary comparison of n elements, (n–1) judgments are made, and $\tilde{\lambda}_{max}$ is the mean value of components $\overline{\lambda}_{max}$, which are obtained in the element-by-element division of components of vector $A\mu^T$ into the components of vector μ. If η does not meet the requirements of accuracy, then matrix A is corrected with regard to the resulting vector μ. Defined vectors:

$$\mu_i=\left\{\mu_{\tilde{C}(\gamma_i)}(x_j)\right\},\ j=\overline{1,n};\ i=\overline{1,5}, \tag{27}$$

that match fuzzy variables $\gamma_{n,1}$, $\gamma_{n,2}$ of linguistic variable β_n and $\gamma_{c,1}$, $\gamma_{c,2}$, $\gamma_{c,3}$ of linguistic variable β_c, are normalized. A graphic representation of the membership functions of fuzzy subsets, which correspond to the fuzzy variables defined here, is shown in Fig. 3, 4.

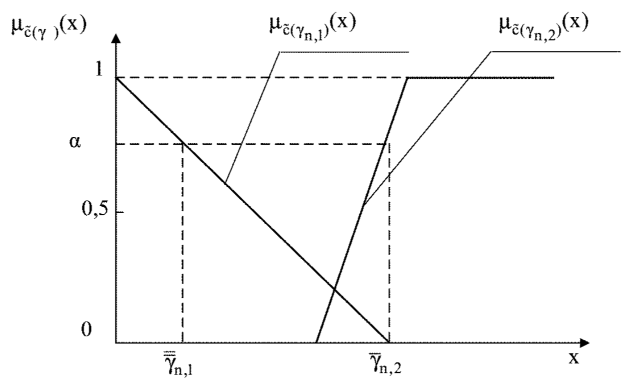

Fig. 3. Membership functions of fuzzy variables $\gamma_{n,1}$, $\gamma_{n,2}$

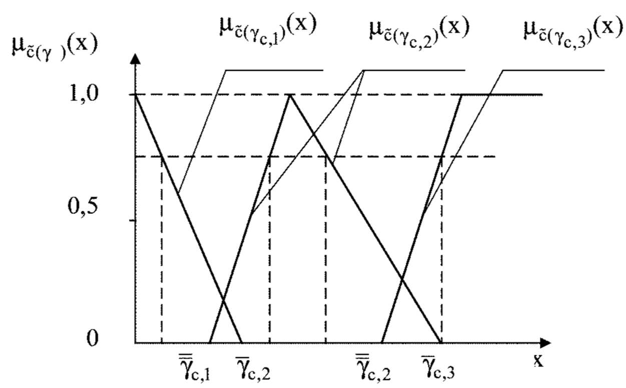

Fig. 4. Membership functions of fuzzy variables $\gamma_{c,1}$, $\gamma_{c,2}$, $\gamma_{c,3}$

As the dimensionality of domain for determining X of linguistic variable β_n – "demand in the market for armaments", we may accept a price of the UAV prospective model unit in the market. As the dimensionality of domain for determining X of linguistic variable β_c – "competitiveness", we may take a ratio of the price of a UAV prospective model unit in the market of opponent to the price of a model unit in the market of operating side (a side, which is considering a solution to the problem).

To obtain membership functions of fuzzy variables $\gamma_{n,1}$, $\gamma_{n,2}$, $\gamma_{c,1}$, $\gamma_{c,2}$, $\gamma_{c,3}$, we should also determine the level of membership functions:

$$\alpha=\mu_{\tilde{c}(\gamma_{n,1})}(x)=\mu_{\tilde{c}(\gamma_{n,2})}(x)=$$
$$=\mu_{\tilde{c}(\gamma_{c,1})}(x)=\mu_{\tilde{c}(\gamma_{c,2})}(x)=\mu_{\tilde{c}(\gamma_{c,3})}(x), \tag{28}$$

which will be matched by the following distinct sets:

for $\gamma_{n,1} - \{0,...,\bar{\bar{\gamma}}_{n,1}\}$; for $\gamma_{n,2} - \{\bar{\gamma}_{n,2},...,\bar{\bar{\gamma}}_{n,2} > \bar{\gamma}_{n,2}\}$;

for $\gamma_{c,1} - \{0,...,\bar{\bar{\gamma}}_{c,1}\}$; for $\gamma_{c,2} - \{\bar{\gamma}_{c,2},...,\bar{\bar{\gamma}}_{c,2}\}$;

for $\gamma_{c,3} - \{\bar{\gamma}_{c,3},...,\bar{\bar{\gamma}}_{c,3} > \bar{\gamma}_{c,3}\}$.

Then, according to the decomposition of problem into hierarchy specified in Fig. 2, all indicators (criteria) will be defined in the fuzzy statements and taken into account in further consideration as the distinct sets (intervals) at accepted value α of their membership functions. At the accepted level of α, we shall define, according to the method of hierarchy analysis, priority predicted UAV model by the indicators C_1^α C_2^α C_3^α C_4^α C_5^α that are described by intervals:

$$\{\bar{C}_c^\alpha,...,\bar{\bar{C}}_c^\alpha\},\ k=\overline{1,5}, \tag{29}$$

and indicators, for which we shall consider appropriate intervals:

$$\gamma_{n,2}^\alpha = \{\bar{\gamma}_{n,2}^\alpha,...,\bar{\bar{\gamma}}_{n,2}^\alpha\} \text{ and } \gamma_{c,3}^\alpha = \{\bar{\gamma}_{c,3}^\alpha,...,\bar{\bar{\gamma}}_{c,3}^\alpha\}. \tag{30}$$

Thus, we examined a decomposition of the problem into hierarchy that reflects the content of multi-criteria optimization problem. The peculiarities of formalization are a fuzzy description of predicted values of basic UAV TTC, which have quantitative and qualitative nature.

5. Results of substantiating a decision on the selection of UAV model for its acceptance for military use

We shall assume that by using information about basic UAV TTC, which is presented in [1, 14], there was conducted an appraisal for the purpose of determining the predicted values for each of the UAV characteristics. When processing expert data, values of each characteristic are represented by a fuzzy subset (a fuzzy triangular number). As for the indicators "high demand in the market for armaments", and "high competitiveness", we considered appropriate linguistic variables. In order to define fuzzy variables of linguistic variables, we constructed membership functions. For three possible promising UAV models, distinct sets of change in the values of indicators at the accepted level of α in the membership functions are given in Table 1.

Table 1

Values of TTC indicators for the UAV promising models

TTC / UAV	C_1^α, min	C_2^α, km/g	C_3^α, m	C_4^α, km	C_5^α, USD thousand	$\gamma_{n,2}^\alpha$	$\gamma_{c,3}^\alpha$
UAV-1	45,...,60	60,...,95	100,...,5000	0,...,10	33,...,35	65,...,70	0,8,...,1,3
UAV-2	45,...,120	40,...,120	100,...,2000	0,...,15	13,...,15	40,...,50	1,1,...,1,5
UAV-3	45,...,120	65,...,130	100,...,5000	0,...,30	13,...,14	50,...,60	1,8,...,2,5

According to the method of hierarchy analysis, identifying a comparative significance of indicators is implied. A binary comparison of indicators is the result of the appraisal. When forming the values of elements that make up the second level of hierarchy, experts were guided by a question. The question is: by how many times is the indicator under consideration more essential (significant) relative to another indicator in terms of ultimate goal. The goal of this level is to define a predicted promising UAV model (Table 2). Table 3 specifies matrix:

$$A = \|a_{i,j}\|,\ i,j=\overline{1,7}, \tag{31}$$

solution of matrix equation:

$$A\mu^T = \lambda_{max}\mu, \tag{32}$$

yields own vector with constants:

$$\mu=\{0.029;0.039;\ 0.051;\ 0.073;\ 0.436;\ 0.149;\ 0.11\}. \tag{33}$$

Table 2

Binary comparison of UAV indicators

General requirements to UAV model	C_1^α, min	C_2^α, km/g	C_3^α, m	C_4^α, km	C_5^α, USD thousand	$\gamma_{n,2}^\alpha$	$\gamma_{c,3}^\alpha$
Flight duration, C_1^α	1	1/3	1/4	1/7	1/5	1/9	1/5
Flight speed, C_2^α	3	1	1/4	1/3	1/5	1/9	1/3
Flight altitude, C_3^α	4	4	1	1/5	1/3	1/7	1/3
Activity range, C_4^α	7	3	5	1	1/4	1/5	1/3
Cost of production, C_5^α	5	5	3	4	1	5	9
High demand in the market for armaments, $\gamma_{n,2}^\alpha$	9	9	7	5	1/5	1	8
High competitiveness, $\gamma_{c,3}^\alpha$	5	3	3	3	1/9	1/8	1

Normalized vector:

$$\mu_i^{n,\alpha} = \mu_i^\alpha \Big/ \sum_{i=1}^{7}\mu_i^\alpha,\ i=\overline{1,7}, \tag{34}$$

takes the form:

$$\mu^{n,\alpha} = \{0.03;\ 0.05;\ 0.06;\ 0.07;\ 0.51;\ 0.15;\ 0.13\}, \tag{35}$$

where it is noted that result $\mu^{n,\alpha}$ matches the level of α, accepted for all indicators, of membership functions to their corresponding fuzzy subsets:

$$\tilde{C}(\gamma_i), i=\overline{1,7}. \tag{36}$$

Let us consider binary relations of benefits in the predicted promising UAV models armament, which make up the content of the third level of hierarchy, from the point of view of one or another indicator, which make up the content of the second level of hierarchy. Such seven matrices are given in Tables 3, 4. Eigenvectors of the respective matrices are also included there:

$$\mu_i^{n,\alpha},\ i=\overline{1,7}. \tag{37}$$

Experts guided by the opinion conduct binary comparisons at the third level of hierarchy. The question is: how many times is the UAV model under consideration appropriate in relation to each indicator of the second level of hierarchy.

For the purpose of maintaining generalized indicators for a priority UAV model, we realized a principle of synthesis, according to which the component of vector of priorities regarding the predicted UAV model is determined by expression:

$$\mu_k^{n,\alpha}=\sum_{i=1}^{7}\mu_{i,k}^{n,\alpha}\mu_i^{n,\alpha},\ k=\overline{1,3}, \tag{38}$$

where $\mu_{i,k}^{n,\alpha}$ is the normalized value of the k-th component of vector of priority of UAV models by the i-th indicator whose values are defined by the α-level distinct interval of membership function; $\mu_i^{n,\alpha}$ is the normalized value of the i-th component of vector of priorities of indicators, by which a decision is made regarding appropriate promising UAV model. To calculate component of μ_k^{α}, the data obtained in Table 1, 2 are conveniently presented in Table 3.

Table 3

Binary comparisons of UAV models in accordance to their indicators

C_1^{α}	UAV-1	UAV-2	UAV-3	$\mu_1^{n,\alpha}$
UAV-1	1	2	0.5	0.286
UAV-2	0.5	1	0.33	0.167
UAV-3	2	3	1	0.547
C_2^{α}	UAV-1	UAV-2	UAV-3	$\mu_2^{n,\alpha}$
UAV-1	1	0.5	5	0.321
UAV-2	2	1	5	0.586
UAV-3	0.2	0.25	1	0.093
C_3^{α}	UAV-1	UAV-2	UAV-3	$\mu_3^{n,\alpha}$
UAV-1	1	2	0.33	0.223
UAV-2	0.5	1	0.25	0.143
UAV-3	3	4	1	0.634
C_4^{α}	UAV-1	UAV-2	UAV-3	$\mu_4^{n,\alpha}$
UAV-1	1	3	5	0.65
UAV-2	0.33	1	3	0.23
UAV-3	1/5	0.33	1	0.12
C_5^{α}	UAV-1	UAV-2	UAV-3	$\mu_5^{n,\alpha}$
UAV-1	1	0.33	5	0.26
UAV-2	3	1	7	0.68
UAV-3	0.2	0.14	1	0.08
$\gamma_{n,2}^{\alpha}$	UAV-1	UAV-2	UAV-3	$\mu_6^{n,\alpha}$
UAV-1	1	2	0.33	0.229
UAV-2	0.5	1	0.5	0.206
UAV-3	3	2	1	0.564
$\gamma_{c,3}^{\alpha}$	UAV-1	UAV-2	UAV-3	$\mu_7^{n,\alpha}$
UAV-1	1	0.14	0.33	0.09
UAV-2	7	1	5	0.71
UAV-3	3	0.2	1	0.2

Then one should make a decision. Of the three samples of UAV, UAV-2 is to be considered as the most appropriate, because the highest $\mu_1^{n,\alpha}$ value is achieved, given the fuzzy nature of values of the indicators.

Table 4

Generalization on the UAV models

Indicator	C_1^{α}	C_2^{α}	C_3^{α}	C_4^{α}	C_5^{α}	$\gamma_{n,2}^{\alpha}$	$\gamma_{c,3}^{\alpha}$	$\mu_1^{n,\alpha}$
Value of priority vector	0.03	0.05	0.06	0.07	0.51	0.15	0.13	
UAV-1	0.286	0.321	0.223	0.65	0.26	0.229	0.09	0.255
UAV-2	0.167	0.586	0.143	0.23	0.68	0.206	0.71	0.527
UAV-3	0.547	0.093	0.634	0.12	0.08	0.564	0.2	0.218

Making such a clear decision under conditions of fuzzy environment, as noted in [17, 18], has appropriate values of effectiveness and risk indicators. In this case, all membership functions of indicators of quantitative and qualitative nature should be brought to one scale of measuring the determination area. Then the indicator of decision-making efficiency is a measure of accuracy of cross section of fuzzy subsets that match the indicators of predicted armament models introduced for consideration.

6. Discussion of results of examining the selection of UAV model for accepting it for military use

The issue of equipping AF with modern UAV and accepting them into service remains unresolved. At present, the need of AFU in UAV is not clearly identified, as well as the approaches regarding the choice of particular models [8, 13]. Articles [10, 11] propose a method of design to the development of model using a team of experts, however, a question of determining the expediency of a given class of UAV is not considered.

It is proposed to select a model of armament based on the set of basic indicators (criteria) that can have quantitative and qualitative nature. We substantiate the necessity of predicting the values of indicators under conditions of nonstochastic uncertainty. It is noted that should the examination utilize statistics, then the task of predicting the given characteristics could be solved under conditions of stochastic uncertainty. In this case, it is necessary to take into account the assumption that the set of factors, which defined statistical significance of TTC, remains unchanged over the predicted time duration. Under such assumption, long-term prediction of the TTC values cannot be considered satisfactory. It is obvious that the prediction of TTC values of UAV samples is considered under conditions of nonstochastic uncertainty based on the setting of appraisal and processing expert data. We proposed a decomposition of problem in hierarchy that reflects the content of multi-criteria optimization problem. The problem is characterized by a fuzzy description of the predicted values of basic UAV TTC, which have distinctly expressed quantitative and qualitative nature and are measured in appropriate magnitudes.

An appraisal was conducted to determine the predicted values for each characteristics of UAV. When processing expert data, values for each of the quantitative characteristics are represented by a fuzzy triangular number. Regarding indicators of qualitative nature, we examined relevant linguistic variables. According to the method of hierarchy analysis, we carried out a comparative assessment of the indicators' significance. In order to obtain generalized indicators for the priority UAV model, the principle of synthesis is proposed.

Thus, as a result of present study, an approach is proposed, which allows the decision maker to interactively find such a variant (alternative) that matches in the best way the essence of the problem and requirements for its solution. It is recommended selecting the most appropriate UAV, for which the largest value of the generalized indicator is achieved given their fuzzy nature. However, a shortcoming of the approach is the need to obtain a large amount of information from experts and the existence of benefits in the best variant among the multitude of existing alternatives. Conducting relevant research would be very expedient to identify viable strategies of modernization, creating new designs, identifying performance indicators, usage risk, determining the best ones for accepting into service by Air Forces, Ground Troops and Naval Forces.

7. Conclusions

As a result of the studies conducted, a comparative evaluation of multi-criteria optimization problems was performed, criteria of which can correspond to factors that reflect both quantitative and qualitative attribute. A method of hierarchy analysis is substantiated for selecting a UAV model for accepting it for military use.

We carried out prediction of TTC values for UAV models under conditions of nonstochastic uncertainty based on the setting of appraisal and processing expert data. Binary comparisons of values by experts are represented in the form of matrices, which makes it possible to define a vector of priorities and a quantitative measure of coherence in experts' judgments.

A decision is substantiated regarding a UAV model by the accepted indicators taking into account the priority vector of basic characteristics. We realized a principle of synthesis, according to which the largest value of the generalized indicator is determined with regard to fuzzy character.

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