

DEVELOPMENT OF METHODS FOR ASSESSMENT AND SELECTION OF UNMANNED AERIAL VEHICLE FOR MINE RECONNAISSANCE

Vadym Neroba¹

¹Department of General Military Disciplines, National Academy of the State Border Guard Service of Ukraine named after Bohdan Khmelnytskyi, Khmelnytskyi, Ukraine
vadym.rostislavovich@gmail.com
ORCID: <http://orcid.org/0000-0002-7232-3285>

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ABSTRACT

Object of research: comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample.

Investigated problem: substantiation of the methodological apparatus for comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample, taking into consideration the presence of both quantitative and qualitative indicators.

Main scientific results: the methods of comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample is developed. The technique is based on an expert method, which allows a drone sample to be evaluated and selected objectively, taking into consideration the presence of both quantitative and qualitative indicators. At the same time, group interaction and discussion of experts are realized. When the judgments do not coincide, an artificial consensus is not imposed. The number of experts is not limited. The experts are not linked in any way. The need to ensure transitive consistency (10–12 %) makes it possible to record attempts by an expert (experts) to artificially overestimate the indicators of one of the drone samples (or the one being evaluated), therefore, the indicators of another sample will automatically deteriorate. The principle of impartiality and fairness is maintained. A well-trained objective coordinator is not required, and the reality is that the absence of the disrupting the problem solution possibility is due to a change in the psychological situation among the experts. **Area of practical use of research results:** humanitarian demining in the interests of ensuring the detection of mines for various purposes by sappers from a safe distance. At the same time, an increase within the probability of mines detecting is ensured due to special equipment installed onboard the drone.

Innovative technological product: a technique has been developed that allows not only assessing the drone samples for mine reconnaissance objectively, but making an objective choice of a sample for specific requirements also.

Scope of application of the innovative technological product: clearance of the terrain remaining after the end of hostilities. With the help of unmanned aerial vehicles, a significant acceleration of the demining process is possible, especially in those territories where mines are installed and being for a sufficiently long time.

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1. Introduction

1.1. The object of research

The object of research is a comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample while using quantitative and qualitative indicators.

1.2. Problem description

The territory of Ukraine, which is considered to be contaminated with explosives, is approximately 16,000 km². By 2019 almost 300 military and more than 2,500 civilians died since the beginning of hostilities due to the explosion of mines and explosive objects.

The threat of a mine situation to troops, border guards and the civilians indicates the existence of a discrepancy. On the one hand, these are requirements for the relevant level of technical means for area engineering reconnaissance conducting for the mines presence, taking into consideration the achievements of modern scientific and technological progress. On the other hand – the

moral obsolescence of ground-based technical means of mines searching left over from the times of the Soviet Union.

Elimination of this discrepancy is possible through the development of more effective technical means of engineering reconnaissance of mines. New approaches are needed for timely and safe remote detection of mines, taking into consideration the latest achievements of scientific and technological progress.

One of these innovative approaches was the idea of using an unmanned aerial vehicle (hereinafter – UAV) for mine reconnaissance. The payload of the drone is a view (with image formation) technical means of mine reconnaissance.

With the help of such reconnaissance drones, it is possible to accelerate the demining process significantly, especially in those territories where mines have been installed and being for a sufficiently long time. Such studies are currently being carried out by the scientists of a number of leading countries of the world: the USA, Great Britain, Israel, Russia, China, Switzerland, etc.

The use of specific technical means of UAVs for mine reconnaissance is an urgent dimension of scientific research. This requires the development of the methods for comparative assessment and selection of UAVs based on the results of the study of system analysis.

1. 3. Suggested solution to the problem

A number of Ukrainian and foreign specialists and scientists were involved in various issues related to research on the use of unmanned aircraft for solving the problems of military facilities reconnaissance: A. Ananin, L. Artiushin, M. Dougherty, V. Kirilenko, V. Kolesnikov, M. Mitrakhovich, S. Mosov, S. Saliy, A. Samkov, A. Selyukov, V. Silkov, A. Feschenko and others.

S. Mosov and V. Kolesnikov in their work [1] gave the system requirements for the selection of unmanned aerial systems for performing reconnaissance and surveillance tasks. At the same time, these requirements are of a general nature, although they can be used to determine quantitative indicators for evaluating UAV samples.

A team of authors in [2] presented the results of research related to unmanned aerial systems from the standpoint of a comparative assessment of their combat capabilities. The methodological approaches proposed in [2] do not consider the issue of assessment and sampling of UAVs with specified equipment for reconnaissance of mines.

A team of authors in [3] analyzed the use of unmanned aircraft in military conflicts of our time, highlighting the features of the use of unmanned aircraft systems of various purposes. At the same time, the issues of using UAVs for detecting mines are not covered in the monograph.

A feature of work [4] is the mathematical apparatus of multi-criteria choice of reconnaissance unmanned aircraft systems. At the same time, the given mathematical apparatus uses only quantitative indicators.

A. Ananiev in [5] proposed a set of tactical and technical requirements for unmanned aircraft systems and defined their tasks in the system of protecting the state border. Among the tasks, the detection of mines is not defined, which today is important for the protection of the state border on the south-eastern border of Ukraine.

In collective work [6] the authors provide approximate calculations of the main parameters and characteristics of unmanned aerial vehicles, which do not take into consideration the tasks of conducting aerial reconnaissance (observation).

V. Neroba in [7] systematized the conditions and factors that would affect the specific technical means of UAV in terms of mines reconnaissance, allowed to determine the quantitative parameters for assessing the samples of UAVs.

M. Dougherty [8] cited the features of the use of unmanned aircraft in local wars and conflicts in the civilian sphere, without parameters systematizing, which can be used to assess and select samples of unmanned aerial vehicles.

The analysis results show that the issue of using the specific technical means of reconnaissance (hereinafter – STMR) installed on UAVs to solve the tasks of mines reconnaissance as objects of aerial reconnaissance remains in the topical arsenal. Only quantitative indicators are used to assess the UAV. The issues of assessment and selection of UAVs for mine reconnaissance require research. This requires the development of a comparative assessment methods and the choice of a

UAV model, on which specific technical means of mine reconnaissance are installed, while taking into consideration quantitative and qualitative indicators.

The aim of the article. To develop a methods for comparative assessment and selection of an UAV sample, on which STMR are installed for mine reconnaissance, while taking into consideration quantitative and qualitative indicators.

2. Materials and methods

The development of the methods for the comparative assessment and selection of an UAV sample for mine reconnaissance based on the results of the study of system analysis methods.

3. Research results

One of the specific features of the task of comparative assessment and selection of a specific UAV sample from a certain set of existing is a significant number of possible alternative solutions based on the indicators of their technical improvement.

To compare several samples, methods of expert assessments are most often used, as well as theoretical methods associated with solving single-criterion or multi-criteria problems.

Objectification of the selection of UAVs for mine reconnaissance is aimed, firstly, the application of a systematic approach in the process of assessing various UAVs, and, secondly, the introduction or development of new effective methods for comparing and selecting UAVs.

To ensure objectivity in the assessment and selection of UAVs for mine reconnaissance, it is advisable to develop a method of comparative assessment and selection based on the results of the study of system analysis methods.

One of these methods is the rather well-known Delphi method, which is a method of establishing expert judgments on the basis of the anonymity of experts and their physical separation, as well as the presence of controlled feedback [9]. To maintain anonymity and physical separation, this method aims to avoid some of the potential pitfalls of group decision making, and the purpose of feedback is to allow each expert to read the average opinion of other experts.

If there are sufficient positive aspects, the method has corresponding disadvantages. The first drawback should be attributed to the fact that the separation of experts practically excludes the possibility of the emergence of new approaches to solving the problem, which can be developed and tested in the course of discussions. Another disadvantage lies in the way of constructing the questionnaire, according to which the survey of experts is carried out. If the questionnaires are not constructed sufficiently, then the conclusions of the experts who answer the question will also be not objective due to the fact that the conclusions are actually determined by the questions that are asked.

Another well-known systemic method of assessment and selection is the Strategic Assumption Surfacing and Testing (hereinafter – SAST) method, which is based on preliminary “polishing” of assumptions (elimination of inconsistency), which are subsequently used to solve the problem, as well as their ranking [10]. The method is well adapted to the analysis of poorly structured problems, in which the development of a solution is based on acutely conflicting assumptions. However, it requires such an objective arbiter, proficient in the art of interpersonal dialogue and experienced in group dynamics theory. Otherwise, the application of the SAST method is doomed to failure. Moreover, the use of the method requires the involvement of a sufficiently large number of experienced qualified experts.

Another systematic procedure is the hierarchy analysis method (hereinafter – HAM) [11]. In contrast to the Delphi method, HAM supports group interaction and discussions. Thus, during exploration of the assumptions underlying individual decisions, new and important knowledge emerges.

The expediency of this approach is confirmed by the experience of conducting business games during the USSR period [12]. In case of disagreement, the HAM does not impose an artificial consensus, since it does not withdraw, but takes into consideration the opinions that fall out of the general channel in the calculations (the value of the discrepancy is allowed).

Comparison of HAM with SAST allows to conclude that they are similar at the stage of the problematic task structuring. At the same time, a well-trained objective coordinator is not required, and it is real that there is no possibility of disrupting the solution of the problem due to a change in the psychological situation among experts.

Thus, according to the results of the analysis, it can be concluded that the HAM is the most well-known of the acceptable system methods, which is advisable to use in terms of methods for

assessing and sampling of UAVs for mines reconnaissance developing. The theoretical work [2] confirms this conclusion. The software implementation of the HAM is available online on the Internet resource [13].

The first step of the HAM is to decompose the problem of assessing and selecting a UAV model for mine reconnaissance and presenting it in the form of a hierarchy (**Fig. 1**). At the first (highest) level, there is a common target z – the best UAV model for mine reconnaissance. At the second level, there are indicators $K=\{k_i\}$, which clarify the goal, and at the third (lower) level, there is a set of applicants $A=\{d_j\}$ from among the UAV samples that must be evaluated.

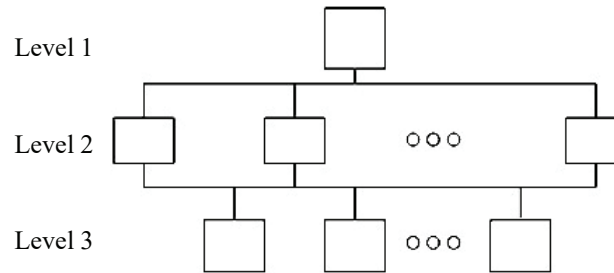


Fig. 1. Scheme of decomposition of tasks, estimation and visualization of UAVs

At the second step, it is necessary to establish the local priorities of the k_j indicators by concluding square matrices of pairwise comparisons (**Table 1**) and conducting expert comparisons using the scale for assessing the relative importance w (**Table 2**). Square matrices are inversely symmetric, that is, the matrix element $b_{ji}=w_j/w_i=1/b_{ij}$. Similar matrices should be constructed for paired comparisons of each d_j sample of the UAV at the third level in relation to the indicators k_i of the second level (**Table 3**).

Sets of local priorities are formed from the groups of matrices of pairwise comparisons, indicating the relative influence of a set of elements on an element of the level adjacent from above. The process of forming local priorities is based on calculating eigenvectors for each matrix and normalizing the result to one:

$$u_i = \frac{1}{\sum_{i=1}^s \sqrt{\prod_{j=1}^s \frac{w_i}{w_j}}} \sqrt{\prod_{j=1}^s \frac{w_i}{w_j}}, \quad (1)$$

u_i – the local priority of the i -th element of the column of the matrix of pairwise comparisons; s – the number of elements of the matrix of pairwise comparisons in the column.

Table 1

Setting local priorities for indicators k_j

Indicators	k_1	k_2	...	$k_{(n-1)}$	k_n	Local priority
k_1	1	w_{k_1}	...	w_{k_1}	w_{k_1}	u_{k_1}
		w_{k_2}	...	$w_{k_{(n-1)}}$	w_{k_n}	
k_2	w_{k_2}	1	...	w_{k_2}	w_{k_2}	u_{k_2}
	w_{k_1}			$w_{k_{(n-1)}}$	w_{k_n}	
...
$k_{(n-1)}$	$w_{k_{(n-1)}}$	$w_{k_{(n-1)}}$	...	1	$w_{k_{(n-1)}}$	$u_{k_{(n-1)}}$
	w_{k_1}	w_{k_2}			w_{k_n}	
k_n	w_{k_n}	w_{k_n}	...	w_{k_n}	1	u_{k_n}
	w_{k_1}	w_{k_2}		$w_{k_{(n-1)}}$		

Table 2The scale for assessing the relative importance w

w	1	3	5	7	9	2, 4, 6, 8
Advantage degree	Equal importance	Moderate importance	Essential	Significant	Very strong	Intermediate

Table 3

Pairwise comparison matrices

k_1	$d_1 d_2 \dots d_m$	Priority vector	k_2	$d_1 d_2 \dots d_m$	Priority vector
d_1	$1 \frac{w_{d_1}}{w_{d_2}} \dots \frac{w_{d_1}}{w_{d_m}}$	$u_{k_1 d_1}$	d_1	$1 \frac{w_{d_1}}{w_{d_2}} \dots \frac{w_{d_1}}{w_{d_m}}$	$u_{k_2 d_1}$
d_2	$\frac{w_{d_2}}{w_{d_1}} 1 \dots \frac{w_{d_2}}{w_{d_m}}$	$u_{k_1 d_2}$	d_2	$\frac{w_{d_2}}{w_{d_1}} 1 \dots \frac{w_{d_2}}{w_{d_m}}$	$u_{k_2 d_2}$
...
d_m	$\frac{w_{d_m}}{w_{d_1}} \frac{w_{d_m}}{w_{d_2}} \dots 1$	$u_{k_1 d_m}$	d_m	$\frac{w_{d_m}}{w_{d_1}} \frac{w_{d_m}}{w_{d_2}} \dots 1$	$u_{k_2 d_m}$
...	$d_1 d_2 \dots d_m$	Priority vector	k_n	$d_1 d_2 \dots d_m$	Priority vector
d_1	$1 \dots \dots$	...	d_1	$1 \frac{w_{d_1}}{w_{d_2}} \dots \frac{w_{d_1}}{w_{d_m}}$	$u_{k_n d_1}$
d_2	$\dots 1 \dots$	...	d_2	$\frac{w_{d_2}}{w_{d_1}} 1 \dots \frac{w_{d_2}}{w_{d_m}}$	$u_{k_n d_2}$
	$\dots \dots 1$	...	...	...	...
d_m	...	...	d_m	$\frac{w_{d_m}}{w_{d_1}} \frac{w_{d_m}}{w_{d_2}} \dots 1$	$u_{k_n d_m}$

In the process of pairwise comparisons, to identify and eliminate possible violations of transitive consistency, the value of the consistency index r should be determined to calculate the consistency ratio χ :

$$r = \frac{\lambda_{\max} - s}{s - 1}, \quad \chi = \frac{r}{r_0} 100 \%, \quad (2)$$

r – the index of random consistency [14]:

$$r_0 = 1.67e^{-\frac{1.0808}{s}}, \quad (3)$$

λ_{\max} – the maximum eigenvalue of the matrix:

$$\lambda_{\max} = \sum_{i=1}^s u_i \sum_{j=1}^s \frac{w_j}{w_i}. \quad (4)$$

The value χ should not exceed 10–12 %, otherwise it will be necessary to additionally check the judgments of experts [11].

In the case where experts do not have sufficient experience in making judgments or a sufficient level of professional training to carry out the process of setting local priorities, the criteria should be pre-ranked.

The penultimate step in determining z is the implementation of the principle of synthesis. The priorities are synthesized starting from the second level down. Local priorities $u_{k_i d_j}$ are multiplied by the priority u_{k_i} of the corresponding indicator at the highest level and summed up for each element in accordance with the criteria that this element affects:

$$(l_{d1}, l_{d2}, \dots, l_{dm}) = (u_{k1}, u_{k2}, \dots, u_{kn}) \begin{pmatrix} u_{d1} & u_{k1d1} & \dots & u_{k1dm} \\ u_{k2d1} & u_{k2d2} & \dots & u_{k2dm} \\ \dots & \dots & \dots & \dots \\ u_{knd1} & u_{knd2} & \dots & u_{kndm} \end{pmatrix}. \quad (5)$$

The procedure for synthesizing local priorities is carried out to the lowest level, as a result of which the global priorities l_j of each UAV sample – d_j are determined. The ranking of the obtained priorities allows to determine the UAV sample with the highest priority value, which will be the most pleasant among the UAV samples that are evaluated.

4. Discussion of research results

The proposed technique allows, firstly, not only to evaluate the UAV samples for mine reconnaissance objectively, but to carry out an objective selection of the UAV sample also. Secondly, the need to ensure transitive consistency makes it possible to record attempts to artificially overestimate the indicators of one of the UAV samples (or the one being evaluated), therefore, the indicators of another UAV sample will automatically deteriorate and the consistency ratio will go beyond the acceptable limits. This allows the principle of impartiality and fairness to be maintained.

When applying the methods, it is proposed to add the following to the composition of indicators $K=\{k_i\}$, which clarify the goal – the choice of a UAV model for mines reconnaissance: the presence of a stabilized platform on board the UAV sample for placing a STMR; maximum payload weight of the UAV sample; operating temperature (winter, summer) of the UAV sample; time spent in the air of the UAV sample; controllability of the UAV sample by the external pilot (pilot-operator); purchase cost of the UAV sample; the cost of operating a UAV sample; the maneuverability of the UAV sample; resistance of the UAV sample to wind gusts; maintainability of the UAV sample; operational reliability of the UAV sample; diagnostic ability to the state of a UAV sample.

The composition of indicators $K=\{k_i\}$ may vary depending on the goal being achieved.

The technique can be applied in the context of comparative assessment and selection of UAVs for mines reconnaissance, which are equipped with STMR: RGB– cameras, infrared cameras, multi- and hyper spectral cameras.

To ensure the objectivity of obtaining the results of applying the methods, the value of the agreement ratio should not exceed 10–12 %.

The technique can be used in conditions when it is necessary to evaluate each (or one) UAV sample. In this case, a “normative” UAV model should be used as an additional UAV sample. After determining the global priority of the “normative” UAV sample, the level of the UAV sample is compared, evaluated relative to the normative by calculating the difference between the global priorities of the “normative” UAV sample and the UAV sample estimated, or calculating the percentage between them.

The direction of further research should be considered the development of recommendations for organizing the training of external pilots and UAV operators for mine reconnaissance. Another promising area may be the development of recommendations for technical operation of an unmanned aircraft complex designed organizing to carry out mine reconnaissance tasks.

5. Conclusions

A methods of comparative assessment and selection of a UAV sample for mine reconnaissance have been developed, based on the well-known expert method for analyzing hierarchies. The methods have several advantages. The first is to support group interaction and discussion. Second, if the judgments do not coincide, an artificial consensus is not imposed, because opinions that fall out of the general channel in the calculations are not withdrawn, but taken into consideration. Third, a well-trained objective coordinator is not required, and the reality is that the lack of the possibility of disrupting the solution of the problem is due to a change in the psychological environment among experts. Fourth, both quantitative and qualitative indicators are compared simultaneously through quantitative formalization.

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