Assessing the Readiness of UAS Operators Based on the Simulator Training Results

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Abstract

The paper studies the problem of assessing the preparedness of an unmanned aerial system (UAS) operator, which in recent years has become of great importance for achieving several civil and military goals. Since the use of modern technological UAS controls is characterized by a significant potential risk, the requirements for a person operating a similar system are increasing. The study offers a comparative analysis of methods for assessing the readiness of an operator to operate a UAS based on the concepts and methodology of multi-criteria optimization, which allow for taking into account some conflicting and multiple goals. The study developed a new methodology based on the operator's knowledge, skills, and psycho-physiological factors. This methodology involves an automatic assessment of readiness also new users trained to operate several unmanned vehicles. It can be helpful to form an operator profile to make the right choice.

Keywords

Unmanned Aerial System, multi-criteria optimization, multi-attribute decision making

1. Introduction

The most causes of accidents air crashes in the last decade include [1, 2]:

- human factor (human errors) is up to 80% (crew or dispatcher control errors, feeling unwell or pilot fatigue, etc.);
- malfunction of equipment (breakdown of onboard technical, poor fuel quality) is up to 30%;
- environmental impact (fog, rain, cold snap, high humidity, snowstorm) is up to 20%;
- others (terrorist act, sabotage, unexplained) is up to 10%.

The data presented show that more than half of all aircraft accidents occur because of human errors, in most cases committed by crewmembers.

The main causes of emergencies and disasters:

- violation of piloting rules, insufficient qualification of pilots for several aircraft models;
- erroneous actions of the crew in difficult weather conditions;
- fatigue of crew members, problems with the physical and psycho-emotional state;
- ground control service errors;
- poor quality of aircraft maintenance or its absence;
- loss of control when entering a zone of high turbulence;
- act of terrorism.

Also, catastrophes often occur in a controlled flight in a collision with the ground, which is caused by the loss of spatial orientation of the aircraft.

The conclusion that can be drawn from the analysis of the presented facts is that the causes of aviation accidents are mainly related to the activities of the pilot, who is a main element of the man-machine system.

An effective solution for the pre-flight training of a pilot is to work with a computer simulator that is adequate for the apparatus on which he will have to perform real tasks in flight [3]. This is dictated,

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first, by the complication of onboard systems, the improvement of control systems, and ensuring comfortable conditions for managing the aircraft. In addition, modern technologies make it possible to simulate scenarios and situations in which many aviation specialists: pilots, air traffic controllers (ATC), Unmanned Arial Vehicle (UAV) operators, or collaborative decision-making (CDM) of pilots, ATCs, UAVs operators, which especially important in emergencies [4; 5].

The simulator provides the pilot with hardware equipment and virtual means of modeling various flight conditions. Computer simulators can be used not only to acquire specific skills necessary for managing the aircraft but a means of assessing the level of training and advanced training of the pilot [6]. Modern simulators can model different flight situations and monitor and diagnose the emotional state of learners in training. Modeling situations of virtual reality (VR) using the Integrated Virtual Training and Education System (IVTES) for collaborative work of pilots, dispatchers, UAV operators, and engineering staff have possibly solved joint different tasks from normal situations to complex conditions for flight and emergencies too [6; 7].

The approaches which provide safe, thoughtful, and educational practices in a risk-free environment are considered. In addition, the simulator allows for the repeatability of practice exercises, can safely test different levels of training of learners, provides immediate feedback if necessary, and guarantees the performance of standardized experience for all trainees. As is known the quality of simulation situations depends on the availability of the required equipment. Flight simulators have specific equipment and are expensive equipment. For the approach to be effective and increase the likelihood of acquiring knowledge, trainees must receive immediate feedback, and the simulation must evoke realistic sensations and appropriate responses.

The most obvious purpose of using simulation training is to act in situations where the lack of knowledge and skills can lead to serious consequences. In addition, this approach to training is useful when a large number of trainees get enough practice in the workplace. The creation of an effective training system for aircraft pilots and UAV operators requires specialists in the field of situation modeling, methods of cognitive analysis, design of processes and devices, theories of automatic control and artificial intelligence (AI), as well as statistical data processing [5; 6; 8].

2. Related Works

To date, several detailed reviews have been made that make it possible to judge the existing methods and criteria for training personnel [3; 7; 8] in controlling the flight of an aircraft, helicopter, or drone. The review's authors [3] found that most teaching methods do not have interactivity, are poorly focused on professional activities, and technological novelties to create a new quality of education are also formulated. Methods for assessing the training quality based on the multi-criteria optimization methods are presented in the review [7; 8]. As can be seen from the review, there is no universal approach to the problem under consideration, and the choice of a specific solution depends on the type of problem, the developer's interests, and the distribution conditions of the developed application. The need to integrate Operator Training Systems (OTS) with VR in operator training simulators, their advantages, the role of training assessment methods, and future areas of their application are discussed in the review [7; 9].

The criteria approach to the problem of training operators is presented in papers [10 - 13]. Some specific criteria and algorithms for assessing the pilot's ability to fly a helicopter, taking into account the optimal time distribution between the pilot's training and his performance activities, are considered in [10]. Criteria for evaluating the activities of specialists in the maintenance and operation of UAVs, taking into account the balance between theoretical and practical training of UAV operators, are presented in [11]. The integration of multi-criteria decision-making for the allocation of reserves and methods for optimizing the network structure has been proposed in [12]. The relevance of professional training of junior specialists based on factor analysis, taking into account the personal approach, is presented in [4; 13].

The effects of the implementation of simulator practices are presented in [14 - 18]. A human-oriented approach assessing the training quality based on the simulator training, as an additional measure for training personnel in various industries, and its results are presented in [6; 7; 14]. The effectiveness of Operator Training Simulators (OTS) in the chemical industry, as well as available commercial software packages for creating OTS, are reviewed and discussed in [15]. The practical assessment of the usefulness of the virtual reality system was tested on different groups of trainees. Thus, according to the authors of [16], a group performing work on a real robot, and trained on a simulator showed better results compared to persons who did not take part in them. The authors of [17] presented the results of the training process in three groups, where the usefulness of the simulator was also confirmed. The synergy effect between virtual reality and robotics is presented in [18].

Some results of training groups of employees are presented in [5; 19 - 23]. The concept of training, the implementation of which made it possible to identify several successful behavioral strategies that ensure the safety of a critical object in extreme situations by a team of dispatchers, is described in the paper [19]. The study [20] discusses the estimation of the east and north components of wind speed from the results of a pilot observation and a wind field profiler model. A study of readiness to respond to mass natural disasters by a group of medical workers based on a questionnaire is presented in [21]; the results of training a group of medical workers using virtual training tools are shown in [22]. Aviation Systems as Sociotechnical Systems have two main common features: advanced technologies and high-risk activities are considered in [23] and taken into account when decision-making other than separate professional factors (experience, knowledge, skills) also the non-professional factors (individual psychological, psychophysiological, and socio-psychological).

The papers [24 - 26] present the work carried out at the National Aviation University aimed at creating a UAV control simulator complex. The analysis of the presented results shows the expediency of further studying the tools using the means of the virtual world and assessing the professional skills of the trainees to assess their qualifications in effective group interaction.

3. Background

Assessing the pilot's readiness to perform tasks as intended is associated with taking into account several conflicting factors obtained because of a series of measurements [11]. There are some approaches to solving this problem, which are based mainly on the methods of multi-criteria decision-making and methods of multi-objective optimization [8].

Decision-making on a set of established criteria is a systematic procedure that helps to choose the most preferable alternative possible in an uncertain situation. As a rule, there is no optimal solution to the problem of choice, and the solution depends on the decision-maker's preferences.

In contrast to the decision-making problem, multi-criteria optimization uses mathematical optimization procedures similar to the single-criteria case. In this case, the transformation of a multi-criteria problem into an optimization problem with one criterion is performed. However, the resulting solution to the optimization problem still depends on the parameters set by the user [8].

3.1. Multi-Criteria Decision-Making

Multi-attribute Decision Making (MADM) problems with a homogeneous data type use two main approaches. In the first one, the data is reduced to a single type of input parameter, and then a decision rule is built according to the classical MADM methods. The second approach assumes mixed input parameters. In this case, the decision rule is a binary relation that allows you to select a subset of alternatives from the original set. You should expect the same result when solving the problem, but the first approach looks simpler and clearer. The most common MADM methods are considered the Simple Weighted Addition (SWA) Method, Analytic Hierarchical Process (AHP), and anticipatory methods such as Elimination and Choice Translating Reality (ELECTRE).

Solving a decision problem in AHP begins with building a hierarchical structure that includes purpose, criteria, alternatives, and other factors that influence a choice. This structure should reflect the presentation of the problem by the decision maker.

Next, priorities are determined to establish the relative importance or significance of the elements of the constructed structure, using the paired comparisons procedure. The dimensionless nature of priorities makes it possible to compare heterogeneous factors, which is a distinctive feature of AHP.

At the next stage, a linear convolution of priorities along the hierarchy is performed, because of which the priority value is determined for each alternative to the decision to the main goal. The best alternative is the one that gets the highest priority value. The final decision is made if the constructed structure meets the consistency criterion.

The elimination and choice translating reality (ELECTRE) method provides an ordering of alternatives presented in quantitative and qualitative form. The choice of an alternative is carried out according to the degree of preference. To do this, the method uses the indexes of consistency, discordance, and threshold values. The index value is in the range (0–1), which makes it possible to evaluate the reliability of each relationship and is a test indicator for each alternative. Global consistency is estimated by the C_{ik} indicator, which confirms the consistency of all criteria under the hypothesis of the superiority of the alternative A_i over A_k. It is calculated like this

$$C_{ik} = \frac{\sum_{j=1}^{m} w_j c_j(A_i A_k)}{\sum_{j=1}^{m} w_j}, \tag{1}$$

where w_j is the weight of the jth criterion; m is the total number of criteria; i, k is the estimated pair of alternatives; $c_j(A_iA_k)$ is the index of agreement that the alternative A_i is better than the alternative A_k in terms of criterion j. The ELECTRE method generates a system of binary superiority relations between alternatives.

The considered methods assume the presence of important data for the input parameters, which can inspire confidence in the decisions made. Different initial assumptions and constraints can lead to inconsistency in the solutions obtained by different MADM methods. To ensure the decision is made, it is proposed to use several approaches. Obtaining similar results by different MADM methods will ensure that the alternative with the highest rating is preferred because it has a high level of reliability.

3.2. Multi-Criteria Optimization

Multi-criteria optimization methods are classified according to the articulation of preferences in solving engineering problems. These include:

- Methods for a priori selection of preferences. Following these methods, it is proposed to set preferences that express the relative importance of different goals. These methods are weighted minimum and maximum, weighted product, lexicographic, linear aggregation/weighted sum, compromise programming, checkpoint, constrained objective function, desirability-based approach, goal programming, exponential weighting, etc.
- Methods for a posteriori selection of preferences. These methods are used when it is difficult to accurately determine decision function. Then it becomes expedient to choose from several already available solutions. Similar difficulties can be overcome by methods of multi-criteria optimization such as genetic algorithms, methods of normal constraints (NC), normal boundaries (NBI), intersections, and physical programming.
- Methods without highlighting preferences. Most of these methods represent some simplification with a priori preference extraction, which consists of taking the weight coefficients equal to one. Among them are the global criterion method, the minimum-maximum, the compromise function, the target sum, and the target product.

The statement of the problem of multi-objective optimization is written in the form

$$y = \min_{x} G(x) = (g_1(x), g_2(x), \dots, g_n(x))^T, \tag{2}$$

where $x = (x_1, \dots, x_m)^T$ is the preferred solution vector. We introduce k constraints c_i, $c_i \leq 0$, $i=1, \dots, k$, and n goal functions $g_j(x)$, $j=1,\dots, n$.

The problem is to establish an admissible set S of preferred solutions y of the vector $x \in R^m$ that satisfy the constraint vector $G(x) \in R^n$

$$S = \{x \in R^m | G(x) \in R^n\}, \tag{3}$$

In this case, the solution y is a vector satisfying the expression

$$y = \cup_{x \in S}\, g(x), \tag{4}$$

4. Problem Solution

UAV control training requires special tools to prepare the operator for actions in real situations. An important task is to control several UAVs. The complexity of this task is characterized by the multi-variance of situations requiring management decisions and the lack of wide distribution of such tools. It should be noted that the training of the operator and the assessment of his skills is still possible with the presence of a simulator based on virtual reality. In this case, the problem lies in the need to collect adequate data to compile his profile.

To this end, it is necessary to have a game engine that simplifies the learning process to control multiple UAVs. The purpose of the game engine is to create various tasks. The operator draws up a preliminary plan of action. During the plan implementation, random events lead to disrupting the successful mission completion. The operator's actions are perceived as decisions aimed at the successful completion or mission failure. The user's evaluation is based on his decision, knowledge, skills, and abilities. The information received from the simulator is interpreted in a way sufficient to evaluate the user's actions and draw up his profile. The user decisions are documented by a simulator for subsequent analysis and suggestion of corrective actions in the current situation. It is believed that the proposed approach will allow for more accurate profiling of operators.

4.1. UAS Operator Performance Indicators

To create a user profile, it is necessary to have a description of the user based on measurable and understandable indicators of the simulator. To form these indicators, it is necessary to establish independent metrics. It is proposed to assess planning (PS) and monitoring (MS) skills. The first indicator shows the ability to draw up a rational plan aimed at achieving the ultimate goal, and the second indicates the ability to overcome problem situations.

A generalized indicator is also introduced, defined by a train: the ability to plan (*AP*), the ability to manage (*AM*), contact (*C*), and functionality (*F*). Here, contact C denotes the ability to maintain communication with UAVs to solve the target task, and functionality F implies the ability of the operator to correct the initial plan. The impact of the introduced indicators is provided by weight coefficients, which are in the range from 0 to 1, with 0 being the worst and 1 being the best value of the indicator. Therefore, the indicators train (*AP*, *AM*, *C*, *F*), in which each coordinate is the average value of each indicator for all user actions, characterizes the acquired user skills.

4.2. Ability to Plan Metric

The first step in solving a mission is to make a draft plan, which is assigned to determine the trajectory for each UAV by defined waypoints. For example, it is done in the Mission Planner [27], Fig. 1. Planning skills are assessed by the ability to plan (*AP*) metric, which takes into account the time spent planning $t_{UAV}(s)$ of the UAV trajectory and the number of waypoints $W_{UAV}(s)$ entered during this time. The metric is calculated by the formula:

$$AP(s) = \frac{1}{2}\left(\frac{t_{UAV}(s)}{t(s)} + \frac{W_{UAV}(s)}{W(s)}\right) \qquad (5)$$

where $W(s)$ is the total number of waypoints set by the user for situation s, and $t(s)$ is the creation time of the entire mission plan. A high indicator of the values of this metric is not desirable, since further actions are possible related to the clarification of the plan and may lead to a deterioration in the overall indicator characterizing the user's skills.

4.3. Ability to Manage Metric

The ability to manage (*AM*) metric rewards the user for successful actions. The operator’s task is to be able to control the largest possible number of UAVs, return the controlled UAVs to the starting point, and minimize energy costs, including fuel, Fig. 2.

COM3 115200

Distance: 0.7989 km
Prev: 522.46 m AZ: 67
Home: 462.94 m

GEO -35.040907 117.832747 11.40

☐ Grid View KML

GoogleSatelliteMap

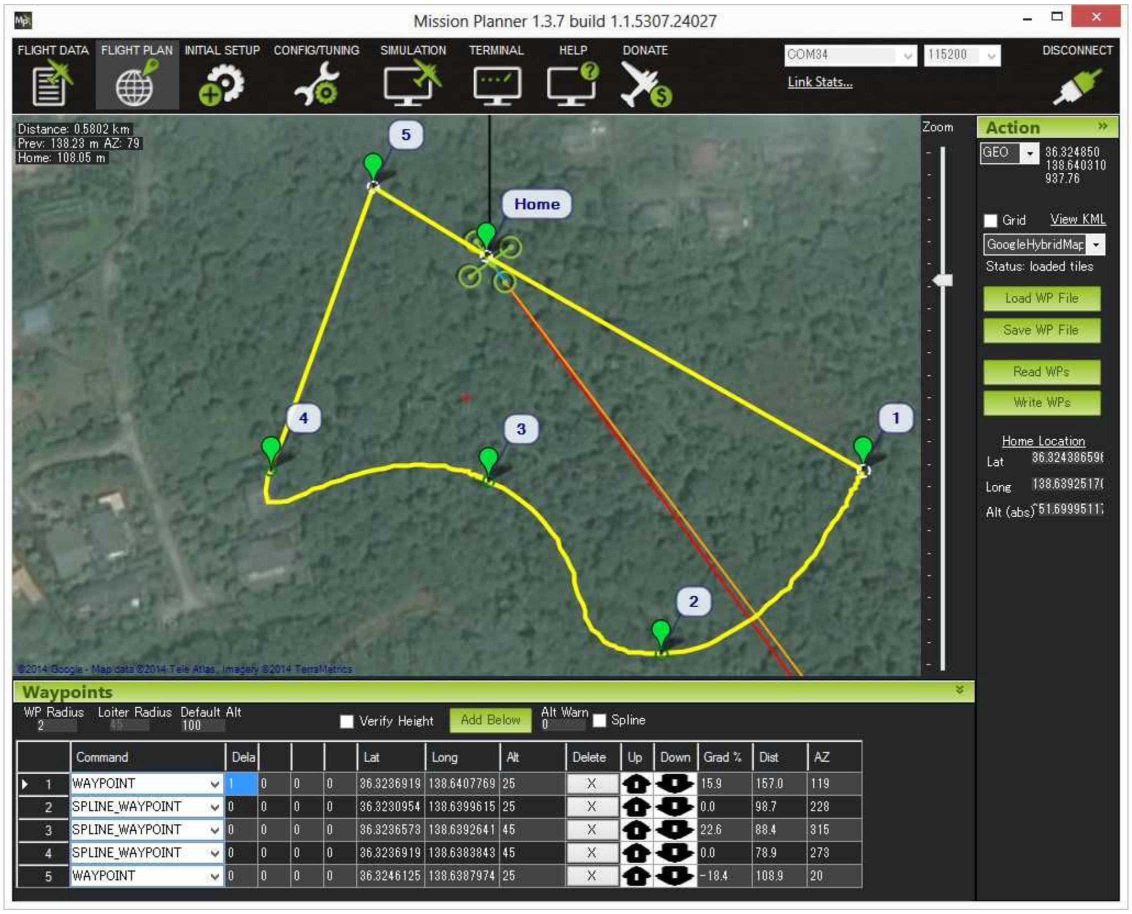
Status: loaded tiles

Home Location
Lat -35.04173272
Long 117.8277683
Alt (abs) 38

WP Radius 2 Loiter Radius Default Alt 100 ☐ Absolute Alt ☐ Verify Height Alt Warn 20

	Command					Lat	Long	Alt	Delete	Up	Down	Grad %	Dist	AZ
1	WAYPOINT	0	0	0	0	-35.0407928	117.8277898	100	X	⬆	⬇	95.7	104.5	1
2	WAYPOINT	0	0	0	0	-35.0406786	117.8260410	100	X	⬆	⬇	0.0	159.7	275
3	WAYPOINT	0	0	0	0	-35.0417239	117.8251612	100	X	⬆	⬇	0.0	141.2	215
4	WAYPOINT	0	0	0	0	-35.0428395	117.8259873	100	X	⬆	⬇	0.0	145.1	149
▸ 5	WAYPOINT	0	0	0	0	-35.0427165	117.8274572	100	X	⬆	⬇	0.0	134.5	84

Figure 1: Setting waypoints on the example of Mission Planner in ArduPilot



Mission Planner 1.3.7 build 1.1.5307.24027

COM34 115200

Distance: 0.5802 km
Prev: 138.23 m AZ: 79
Home: 108.05 m

GEO 36.324850 138.640310 937.76

☐ Grid View KML

GoogleHybridMap

Status: loaded tiles

Home Location
Lat 36.32438659
Long 138.63925170
Alt (abs) 51.6999511

WP Radius 2 Loiter Radius 45 Default Alt 100 ☐ Verify Height Alt Warn 0 ☐ Spline

	Command	Dela				Lat	Long	Alt	Delete	Up	Down	Grad %	Dist	AZ
▸ 1	WAYPOINT	1	0	0	0	36.3236919	138.6407769	25	X	⬆	⬇	15.9	157.0	119
2	SPLINE_WAYPOINT	0	0	0	0	36.3230954	138.6399615	25	X	⬆	⬇	0.0	98.7	228
3	SPLINE_WAYPOINT	0	0	0	0	36.3236573	138.6392641	45	X	⬆	⬇	22.6	88.4	315
4	SPLINE_WAYPOINT	0	0	0	0	36.3236919	138.6383843	45	X	⬆	⬇	0.0	78.9	273
5	WAYPOINT	0	0	0	0	36.3246125	138.6387974	25	X	⬆	⬇	-18.4	108.9	20

Figure 2: Shaping of a spline trajectory by changing the coordinates of a waypoint

The indicator of the ability to manage (*AM*) in a situation (s) is determined by the expression:

$$AM(s) = \frac{1}{3}\left(\frac{D(s)}{N(s)} + \left(1 - \frac{L_{UAV}(s)}{U(s)}\right) + \frac{R_{UAV}(s)}{U(s)}\right) \tag{6}$$

where $D(s)$ is the number of targets identified through detection, $N(s)$ is the number of targets assigned to the current mission, $U(s)$ are controlled UAVs, $L_{UAV}(s)$ is the number of UAVs lost by the user during the mission, and $R_{UAV}(s)$ the number of UAVs that returned at the end of the simulation. The second term, written in parentheses in formula (6), directly characterizes the efficiency of the operator's control stage in solving the target problem. In this case, $L_{UAV}(s) < R_{UAV}(s) \leq D(s)$ is assumed.

4.4. Contact Metric

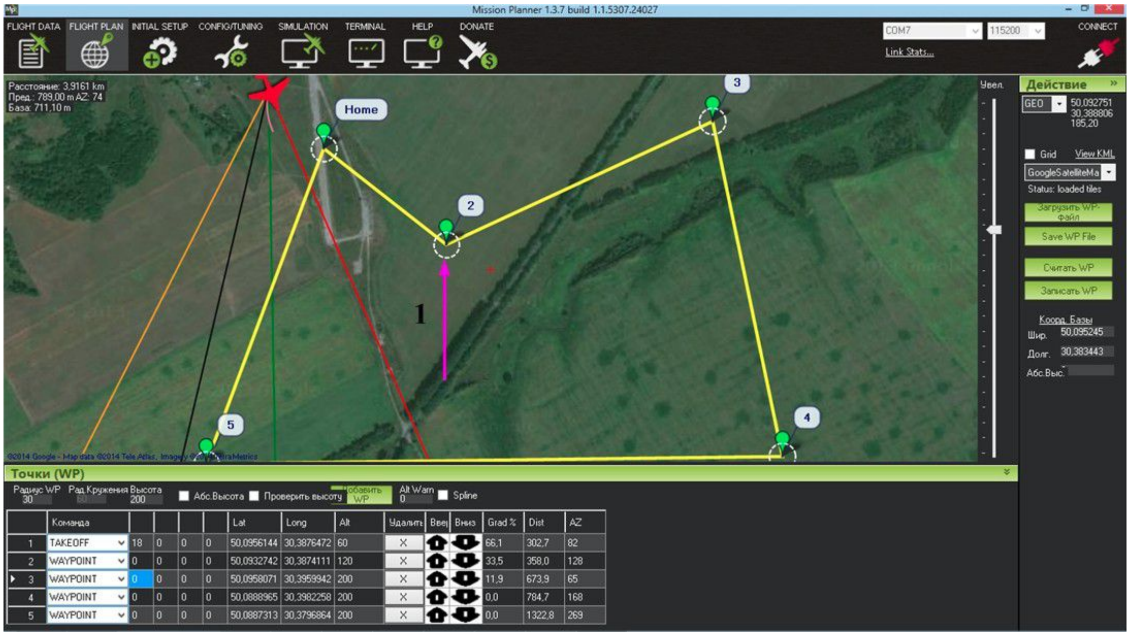
Since the user controls several devices, it is important to know the degree of his contact with the UAV during the mission. The metric is focused on measuring the number of user contacts with all UAVs, determined by the set of contacts $C_U = \{C_{U1}, \ldots, C_{UN}\}$. Here C_{Ui} is the number of user contacts with the ith UAV. This metric is proposed to be calculated as follows:

$$C(s) = \frac{1}{1+\sigma_{C_U}} \tag{7}$$

Here, is the standard deviation of various types of contacts with the UAV. If it is small, the user contacts all UAVs in the same way, and the value of $C(s)$ tends to the maximum value, namely 1.

4.5. Functionality Metric

The user activity is defined by his ability to function (F), i.e. his ability to correct the initial plan. For example, the operator can change the trajectory of the UAV in a mission, i.e. to correct the initial plan by introducing intermediate points, Fig.3.



Расстояние: 3,9161 km
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База: 711,10 m

50,092751
30,388806
185,20

Status: loaded tiles

Шир. 50,095245
Долг. 30,383443

Радиус WP 30
Рад.Кружения 60
Высота 200
Alt Warn 0

	Команда					Lat	Long	Alt	Удалить	Ввер	Вниз	Grad %	Dist	AZ
1	TAKEOFF	18	0	0	0	50,0956144	30,3876472	60	X	⇧	⇩	66,1	302,7	82
2	WAYPOINT	0	0	0	0	50,0932742	30,3874111	120	X	⇧	⇩	33,5	358,0	128
▸ 3	WAYPOINT	0	0	0	0	50,0958071	30,3959942	200	X	⇧	⇩	11,9	673,9	65
4	WAYPOINT	0	0	0	0	50,0888965	30,3982258	200	X	⇧	⇩	0,0	784,7	168
5	WAYPOINT	0	0	0	0	50,0887313	30,3796864	200	X	⇧	⇩	0,0	1322,8	269

Figure 3: Correction of the initial plan by introducing an additional waypoint

So, in the monitoring mode, adjusting the initial plan comes down to adding or changing the coordinates of waypoints or introducing a manual control mode. The last one involves the creation of a completely new plan. The highest functionality is to create a new path, which involves the execution of the "Correct Waypoints" and "Monitoring" modes.

Because the functionality is limited to changing the coordinates of waypoints in the indicated modes, the sets $W_M(s)$, $W_A(s)$, and $W_{MM}(s)$ are introduced, representing the number of operations with waypoints performed in the Monitor, Add waypoint and Manual modes respectively. Then the metric looks like this:

$$F(s) = \frac{aW_M(s)+bW_A(s)+cW_{MM}(s)}{W(s)} \tag{8}$$

where $W(s) = W_M(s) + W_C(s) + W_{MM}(s)$. Weight coefficients a, b, and c are used for proper modes balancing, $a + b + c = 1$, $c > b > a$. This metric reaches its maximum value with a completely changed UAV trajectory. If $F(s)$ is close to zero, the user practically did not change the system functionality, which is typical for a simple mission.

5. Simulation

A generalized criterion for the quality of UAV pilot simulator training is introduced, taking into account the considered parameters for evaluating user skills, which is described by the following expression

$$I = \sum_{i=1}^{N} a_i x_i \tag{9}$$

where a_i is the ith weight coefficient, i=1..4, $a=(AP, AM, C, F)^T$, x_i is the measured parameter value. The weight coefficients satisfy the identity

$$\sum_{i=1}^{N} a_i = 1 \tag{10}$$

In addition, a rating scale is introduced that determines the levels of user training Level 1, Level 2, and Level 3. These levels correspond to a high, medium, and low level of training quality according to the numerical estimates of the indicator (9). The correspondence of training levels to interval values is presented in Table. 1.

Table 1
Rating scale

Value	Level 1	Level 2	Level 3
Criteria	0.1-0.3	0.4-0.7	0.8-1
Category	Low	Middle	High

5.1. Evaluation by AHP approach

Following the analysis of the hierarchies process [28, 29, 30], to determine the numerical values of the weight coefficients for each level, matrices of paired comparisons are compiled. We will consider the tasks of planning and monitoring for the operator to be equivalent at the training stage. Therefore, the coefficients of the first level of the hierarchy are assumed to be equal. With the help of matrices of pairwise comparisons, alternatives are identified, which later determine the weight coefficients of the second level of the hierarchy. The criteria put forward serve as the basis for compiling pairwise comparison matrices.

It is assumed that when assessing planning skills, preference is given to the ability to plan when the objects for future manipulations are motionless, and the ability to manage, contact and functionality are secondary. To evaluate monitoring skills, priority is given to alternatives that play an important role in the operator's actions when controlling moving objects, while the initial stage is secondary. Under the considered approach, weight coefficients are obtained. They are the following

$$a_{AP} = 0.0625, a_{AM} = 0.188, a_C = 0.312, a_F = 0.437. \tag{11}$$

The values of the parameters obtained under the measurements carried out on the simulator and calculated by formulas (5) – (8) for three levels of training are shown in Table 2. At the same time, Level 1 corresponds to the level of initial training, and Level 3 corresponds to the highest level of UAS pilot training.

Table 2
Parameters values

Parameter	*AP*	*AM*	*C*	*F*
Level 1	0.07	0.7	0.5	0.08
Level 2	0.275	0.871	0.909	0.545
Level 3	0.367	0.919	0.99	0.74

Following Table 2 best indicators are UAV pilots who have shown the ability on the third level of training.

5.2. Evaluation by ELECTRE approach

The method also allows you to know the level of pilot training based on the available data. The method application scheme involves four stages. At the same time, in the first stage, it is necessary to have positive weights for each criterion. As weights, we choose the values of weight coefficients (11) obtained by the AHP.

Next, a matrix of agreement indices is constructed according to the ratio

$$c_{jk} = \frac{\sum_{i\in I_{jk}^{+}} a_i + \alpha \sum_{i\in I_{jk}^{\circ}} a_i}{\sum_{i=1}^{4} a_i} \qquad (12)$$

where I_{jk}^{+} is the set of criteria by which the *j*th alternative is better than the *k*th, I_{jk}° is the set that consists of those criteria by which the alternatives *j*th and *k*th are equivalent, α is a parameter that can take the values $\alpha \in \{1,\ 0.5,\ 0\}$ depend on the method modification. In the example under consideration, the choice of this value is not of particular importance, but for definiteness, we will assume α=0.5.

Diagonal values are not alternatives, and they are taken equal to unity. The matrix of agreement indices for the case under consideration has the form:

$$C = \begin{pmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}$$

In the next step, a disagreement index matrix is also constructed, the elements of which establish the superiority of alternative *j* over alternative *k* following the formula

$$d_{jk} = \max_{i} \left\{ \begin{matrix} \text{interval of superiority of the } k\text{th alternative} \\ \text{over the } j\text{th alternative by the } i\text{th criterion} \end{matrix} \right\} \qquad (13)$$

where the superiority interval of the alternative *k*th over the alternative *j*th by the criterion *i*th determines the number of consecutive transitions from class to class that must be carried out for the alternative *j*th to become equivalent to the alternative *k*th by the criterion *i*th, multiplied by the price one such transition. In this case, it is required the values of d_{jk} do not exceed unity. Set the transition interval for criteria *AP* and *AM* to 20 scores and for criteria *C* and *F* to 25 scores, then the disagreement matrix has the form:

$$D = \begin{pmatrix} 1 & 0.25 & 0.5 \\ 0.25 & 1 & 0.2 \\ 0.5 & 0.2 & 1 \end{pmatrix}$$

At the last stage, a decision rule is built, under which the final decision is made regarding the degree of preparedness. By the method, the researcher chooses the numbers $p \in (0,\ 1]$ and $q \in [0,\ 1)$, with the help of which a binary relation is built on the set of alternatives, establishing the superiority of the alternative *j*th over the *k*th, provided that $c_{jk} \geq p$ and $d_{jk} \leq q$. The choice of *p* and *q* values is made from considerations of determining the dominance of the solution, so for the values $p = 0.8$ and $q = 0.2$, it is possible to unambiguously determine the transitivity and dominance of the training levels adopted in the simulation.

6. Discussion

The main ideological content of the work is the assessment of the operator's readiness to perform complex tasks based on cognitive and psychomotor skills obtained in the process of training on the simulator to control a group of UAVs. The methodological basis of the approach is the AHP and ELECTRE methods, which are best suited for the problem of deciding on the degree of readiness of the operator in the conditions of heterogeneity and inconsistency of the influence of the measured factors and allow compiling his training profile.

The initial data for the AHP method are the preferences put forward by the simulator developer in terms of task planning, management, contact, and operator functionality for a fixed task. The assessment of the degree of readiness is done by the formula (9), and following the results of Table 1. The approximate values of the measured parameters are given in Table. 2.

To increase confidence in the decision made, it is proposed to use the ELECTRE method, where each alternative solution is subjected to a consistency check. In this case, the weight coefficients for the AHP method are the initial ones for ELECTRE. The agreed decision is made after calculating the indices of agreement (12) and disagreement (13) and the fulfillment of the binary relations $c_{jk} \geq p$ and $d_{jk} \leq q$. A new aggregated decision-making approach based on the AHP and ELECTRE methods is proposed, it is a greater reliability of the decisions made.

7. Conclusion

Online assessment of learning skills is an important task for operator training in a simulated environment when working in real conditions is associated with the risk of mission failure. The value of training increases significantly in the case of managing a group of UAVs. The paper presents methods that make it possible to form a user profile and observe the growth of skills and abilities that guarantee the operator effective activity when performing actual tasks.

This work shows the possibility of using advanced methods to determine whether a user belongs to a particular group, using the developed descriptive metrics using the AHP and ELECTRE approaches.

User profiles are built on planning and monitoring abilities and skills based on measurable numbers, which are then transformed into a categorical scale. The methodology will be effective for simulators that can simulate tasks with several UAVs when the planning and monitoring tasks are solved in an integrated manner.

Further research is going to aim at expanding the possibilities of planning situations and involve other decision-making methods based on methods of planning and processing the results of experiments [31, 32]. Also, research will be aimed at expanding the possibilities of planning situations, else for decision making in an emergency too. Virtual reality simulation for collaborative decision-making by a group of various aviation specialists (pilots, air traffic controllers, UAV operators, engineers, etc.) in emergencies. As well as involving other decision-making methods based on planning methods and processing of experimental results [31, 32], methods of integration of decision-making models (deterministic and stochastic), and methods of collaborative decision-making in uncertainty [5, 33].

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