Unmanned Aerial Vehicle Flight Risk Assessment Model for Environmental Research on Mountain Terrain

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***Abstract* — A study was conducted on the current problem of developing a fuzzy model for assessing the risks of Unmanned Aerial Vehicle (UAV) flights in mountainous terrain, taking into account risk-oriented factors influencing the flight. As a result, we obtained a quantitative assessment of flight risk and a linguistic interpretation of the level of safety of UAV flight, which will allow a reasonable approach to decision support. For the first time, the study proposed fuzzification of input data using a multidimensional membership function, presented in the form of linguistic estimates of the probability of a risk event and quantitative estimates of the number of "reliability" of the ground control manager's conclusions in his conclusions. For the first time, a generalized step-by-step algorithm for obtaining a quantitative assessment of flight risk and a linguistic interpretation of the level of safety of UAV flight have been constructed. Experimental approbation and verification of the conducted research on test data of UAV flight simulation are carried out. The study will be a useful tool to support safe decisions about UAV flight in different mountainous terrain**

Keywords* — *environmental, risk, experts, decision-making, Unmanned Aerial Vehicle (UAV).

I. Introduction

Every day, the aviation industry faces many risks that can potentially jeopardize the success of operations if not managed adequately. Drones, like other air transport, face many risk-oriented factors influencing the flight safety. Every day, we see more and more use of UAV in the work of various services, or for research purposes. They are successfully used in search and rescue operations, for aerial photography and mapping, operational forecasting and assessment of the consequences of emergencies, monitoring of industrial facilities and natural complexes, delivery of goods, for entertainment purposes, and more. However, flight organizers are not always aware of or understand the possible risks that affect the achievement of flight objectives. Researchers need to objectively assess whether UAVs can be used in specific geographical and meteorological conditions, where UAVs use may be affected by specific orographic turbulence, according to wind speed and direction, terrain complexity, UAV maneuvering location in the area, etc.

In this case, to improve safety, we propose to use methods to support decision-making on identification, assessment, risk management, which will lead to the controllability of UAV flight risk management processes in specific conditions.

In view of the above, there is an urgent problem of adequate risk assessment of UAV flights in mountainous areas.

This study ensures the achievement of the goals of the Global Aviation Safety Plan (GASP), 2020-2022 Edition, Doc 10004, which is in line with the UN Sustainable Development Agenda until 2030, namely: Goal 1 is to achieve the continuous reduction of operational safety risks [1].

The research of this problem is divided into four stages:

1. Analysis of possible threats to UAV flights in mountainous areas and the formation of risk-oriented factors influencing the implementation of UAV flights;

2. Development of a fuzzy UAV flight risk assessment model for environmental research in mountainous areas;

3. Design of UAV flight decision support software;

4. Approbation and verification of fuzzy model in real situations and in different mountain conditions. Software testing by research organizers and ground control station controllers during flights.

In this context, the authors have already conducted a preparatory study of the analysis of possible threats to the implementation of drone flights in mountainous areas and based on the proposed set of evaluation criteria [2].

The aim of the present study is to develop a fuzzy model for assessing the risks of UAV flights in mountainous areas.

The logic of the study is as follows: if the risk assessment of UAV flights in mountainous areas is low, for risk-oriented factors, then we can talk about a high level of safety of UAV flight to achieve the objectives of environmental research.

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II. Literature Review

The level of security of human activity is improving every day by improving technology, data mining and knowledge, artificial intelligence management systems, and others. At the same time, the standards of staff training and safety management have become higher. However, we face many risks that could potentially jeopardize the success of our operations if not adequately managed. One of the key components of measuring the risk of functioning of complex systems is to generate scenarios for the development of key risk factors based on possible threats [3].

The application of UAV improves the quality of monitoring and analysis of the environment in the mountains, which opens up new knowledge. At the same time, UAV flight risk management is an important task. The urgency of this task is proved by significant world research and scientific publications, the need for new tools for environmental research.

UASs have been used for many applications, including monitoring of changes in the morphology of [4] a volcano, landslides, dam and riverbed erosion, slow landslides, risks associated with surface mining [5], slope stability in the vicinity of railways, or speed of glacier movement. The paper [6] presents a study of the use of UAV to assess catastrophic situations in mountainous areas, in order to create a topography to support real-time decision-making, flooding, landslides, flood risk, and others. The use of UAV in mountainous areas to study active fires is described in [7]. The paper [8] analyzes the contribution of the international community of landslide researchers in reducing the risk of natural disasters and risk management using unmanned aerial vehicles. In [9] the advantages of using drones to search for people in the mountains are proved. [10] describes a general overview of unmanned aerial vehicles and their potential in a number of applications of engineering geology. Only [11] presents the architecture, implementation, and control results of the system of planning the path of minimal risk focused on long-range unmanned flights at low altitudes. Instead, in all of these current studies, nothing is said about the assessment of UAV flight risks using fuzzy models and methods.

The construction of a fuzzy model is based on information obtained in an expert manner, which depicts the substantive features of the object under study and is formulated in natural language [12-13]. The description of the object, in this case, is unclear. Therefore, to reflect the knowledge, it is advisable to use the theory of fuzzy sets [14-15]. Thus, there is a transition of knowledge in the classical sense to fuzzy knowledge. As a result, it becomes possible to use the apparatus of fuzzy sets to reveal uncertainty and formalize qualitative information [16-17]. Therefore, information modeling of fuzzy knowledge through the functions of belonging to the criteria will allow a more adequate approach to the problem of evaluation.

Thus, today there is no common approach to assessing the risks of UAV flights for environmental research in mountainous terrain and there is a need to develop a decision support system for the level of safety of UAV flights.

III. Data and Methodology

Let some object of study S, that is the defined mountain area and technical characteristics of UAV, be known, with the global purpose of realization of safe flight of UAV at the researched environment in the mountain area. Also known a set of risk-oriented factors of influence (criteria) $K = (K_1, K_2, \dots, K_m)$, the implementation of UAV flights in a complex system S.

The authors, in the process of the first stage of the researches, analyzed the possible threats of drone flights in the mountains, which is described in detail in [2]. Such threats include: the impact of meteorological threats on the safety of drones; destruction of the drone in a collision with the ground; damage to wildlife; lack of direct contact; specificity of the frequency range; vandalism, abduction, drone shooting.

On the basis of set-theoretic generalization, at the first stage of the research, a set of risk-oriented factors influencing the implementation of UAV flights was proposed [2]:

K_1 – meteorological risks;

K_2 – risks of a UAV collision with the ground;

K_3 – risks of implementation in the animal world;

K_4 – risks of collision in the air;

K_5 – the risks of losing the UAV;

K_6 – frequency range and noise risks;

K_7 – risks of UAV and data destruction by third parties.

Each risk-oriented impact factor (risk criterion) will be assessed in a hybrid manner, based on the experience of experts and the confidence of his reasoning about the possibility of flight. Under the expert in this task, we understand the dispatcher of the ground control point or the organizer of the flight.

Based on experience, skills, and knowledge of flight safety in system S, the ground control manager draws conclusions about the level of probability of a risk event described by criterion K to achieve the target needs of system S. As a result, assigns a linguistic assessment for each risk criterion K, with some term, sets $T = \{t_1;\ t_2; \dots;\ t_l\}$. We offer, for example, the following variables: t_1 – critical level; t_2 – maximum level; t_3 – average level; t_4 – minimum level.

Also, for each linguistic assessment (for each criterion) the expert puts the number of "reliability" q of their reasoning regarding the occurrence of a risk event, from the interval [0; 1], or normalized quantitative risk assessment. To obtain a quantitative assessment of risk, separately for each criterion, we propose the use of intelligent data analysis of those quantities that generate risk, based on the theory of fuzzy sets and membership functions [17]. In our study, we will focus on the indicator of "reliability" of the reasoning of the dispatcher of the ground control point, putting the following content: 0 - the minimum confidence in their conclusions, and 1, respectively - the maximum.

As a result, for each indicator, we obtain: t_i – variable from the term set T for the i-th criterion; q_i – quantitative estimate from the interval [0; 1], the i-th criterion, $i = \overline{1, m}$.

Formally, we present a fuzzy model of risk assessment of UAV flights for environmental research in mountainous areas as follows:

$$\Delta(t;q) \to R(S). \qquad (1)$$

Where Δ is the operator that matches the original value of $R(S)$, with the input variables $t;q$. The input data of the model are t – the conclusion of the dispatcher of the ground control point on the level of probability of occurrence of a risk event described by criterion K to achieve the target needs of the system S; q – the number of "reliability" of the considerations of the controller of the ground control point in their conclusions. At the output of the assessment model, we have: $R(S)$ – the risk of UAV flights to study the environment in the mountains in the system S.

Obtaining the initial estimate $R(S)$ is presented in the form of a step-by-step algorithm.

1 step. Fuzzification of input hybrid data

To do this, each input value$(t_i;q_i)$ corresponds to the value of the membership function of many variables $\mu(x_i)$.

To obtain a normalized estimate of the input data, we construct membership rules. Let the term set of linguistic variables T be represented on some numerical interval, to distinguish the terms $[a_0;a_4]$, where $t_1 \in [a_0;a_1]$, $t_2 \in [a_1;a_2]$, $t_3 \in [a_2;a_3]$, $t_4 \in [a_3;a_4]$. The interval splitting values can be adjusted and changed in the process of using real UAV flight data in mountainous terrain.

Next, we assign estimates O_i, using the linguistic variables T and the values of the partitioning of intervals $[a_0;a_4]$, for example, using the following characteristic function:

$$O_i = \begin{cases} a_1, & if \quad t_1; \\ a_2, & if \quad t_2; \\ a_3, & if \quad t_3; \\ a_4, & if \quad t_4. \end{cases} \quad i = \overline{1,m}. \qquad (2)$$

Without sacrificing generality, the systems analyst may also use other known methods of fuzzy inference systems to aggregate qualitative data [16].

Next, we construct a two-dimensional cone-like membership function to aggregate linguistic evaluation and the certainty of its assignment. The cone-shaped membership function was chosen for the following reasons. For example, a UAV cannot be considered safe if there is a low probability of a risky event, but the confidence of the ground control manager in his conclusions is minimal. In this sense, we have the following idea:

$$\mu(x_i) = \begin{cases} 1 - \sqrt{\frac{\left(O_i - a_4\right)^2}{(a_4)^2} + (q_i - 1)^2}, if\ \varepsilon < 1, \\ 0, \quad \varepsilon \geq 1. \end{cases} \qquad (3)$$

whereO_i, q_i the value of the i-th criterion, and $\varepsilon = \sqrt{\frac{\left(O_i - a_4\right)^2}{(a_4)^2} + (q_i - 1)^2}$.

The center of the cone corresponds to a vector of values, which is approximately equal to the value being modeled. The cone-shaped function determines the uniform change of membership when moving away from the center of the cone according to the scaling parameters.

This will allow you to combine the conclusions of the ground control manager on the level of probability of a risky event and the number of "reliability" of confidence in his reasoning. The membership function constructed in this way indicates that the obtained value of $\mu(x_i)$ will go to 1, if the high level of the i-th criterion.

Presentation of input data in the form of linguistic assessment and confidence in its assignment allows better disclosure of the views of dispatchers. Thus, based on the use of fuzzy sets and multidimensional membership functions, the subjectivity of expert opinions is revealed and the transition from fuzzy expert linguistic and quantitative assessments to normalized and comparable ones is made.

2 step. Introduction of weights

Let the expert for each risk-oriented impact factor (criterion) can set the weights v_i, $i = \overline{1,m}$, from some interval [1; 10]. Otherwise, the criteria may be equally important. Since our estimates $\mu(x_i)$ are normalized, then it is necessary to normalize the weights, for example [14]:

$$w_i = \frac{v_i}{\sum_{i=1}^{m} v_i}, i = \overline{1,m}. \qquad (4)$$

3 step. Derivation of an aggregate risk assessment

Next, we will aggregate the estimates of the criteria based on the expert's opinion. To do this, we build a membership function, as one of the proposed convolutions, depending on the views of the expert on the development of events [15]:

$$R_1(S) = \frac{1}{\sum_{i=1}^{m} \frac{w_i}{\mu(x_i)}}; \qquad (5)$$

$$R_2(S) = \prod_{i=1}^{m} \left(\mu(x_i)\right)^{w_i}; \qquad (6)$$

$$R_3(S) = \sum_{i=1}^{m} w_i \cdot \mu(x_i); \qquad (7)$$

$$R_4(S) = \sqrt{\sum_{i=1}^{m} w_i (\mu(x_i))^2}. \qquad (8)$$

Where $R_1(S)$ is a pessimistic scenario of unfolding events; $R_2(S)$ – cautious scenario of unfolding events; $R_3(S)$ – average scenario of unfolding events; $R_4(S)$ – optimistic scenario of unfolding events; w_i ($i = \overline{1,m}$) normalized weights for each criterion. There is the following subordination between them: $R_1(S) \leq R_2(S) \leq R_3(S) \leq R_4(S)$.

4 step. Defuzzification data and decision-making

Based on the obtained aggregate risk assessment, we draw conclusions for further implementation of UAV flight decisions. Based on the obtained aggregate risk assessment $R(S)$, we present a linguistic interpretation of the level of safety of UAV flight to achieve the objectives of environmental research in mountainous areas, as follows:

- $R(S) \in [0; 0.2)$ – VLS: very low level of UAV flight safety;

- $R(S) \in [0.2; 0.4)$ – LS: low level of UAV flight safety;
- $R(S) \in [0.4; 0.6)$ – AS: average level of UAV flight safety;
- $R(S) \in [0.6; 0.8)$ – AAS: UAV flight safety level is above average;
- $R(S) \in [0.8; 1]$ – HS: high level of UAV flight safety.

Decision-making levels can be adjusted based on the experience, skills, and abilities of research experts. In addition, if there is sufficient data on UAV flights, it is advisable to use machine learning methods, such as artificial neural network [18], logistic regression [15], Support Vector Machine (SVM), random forest, and others. In addition, the levels of decision-making can be changed taking into account additional parameters, such as: UAV technical parameters, flight parameters, meteorological parameters, and others.

IV. Experiments

As an experiment, consider an example of a developed model of risk assessment of UAV flights to study the environment in the mountains. As our comprehensive study is in the second stage, the controller of the ground control point of the UAV flight control provided test input data simulating the flight of the UAV in the mountains. For each risk-oriented impact factor *K* we obtain linguistic estimates *t* (conclusion of the ground control manager on the level of probability of occurrence of a risk event described by the relevant criterion to meet the target needs of system S) and quantitative estimates q (number of "reliability" conclusions). Input data and weights, from the interval [1; 10], will be presented in the form of Tabl. 1., as well as in a graphical interpretation Fig. 1.

TABLE I. Input data

Risk-oriented impact factor (criteria)	w	T	q
K_1 – meteorological risks	10	t_2	0.6
K_2 – risks of a UAV collision with the ground	9	t_3	0.6
K_3 – risks of implementation in the animal world	8	t_4	0.8
K_4 – risks of collision in the air	5	t_4	0.9
K_5 – the risks of losing the UAV	9	t_2	0.9
K_6 – frequency range and noise risks	5	t_4	0.7
K_7 – risks of UAV and data destruction by third parties	4	t_4	0.6

Let's perform UAV flight risk assessment for mountain environment research according to the developed fuzzy model and step-by-step algorithm.

1 step. Fuzzification of input hybrid data

To do this, we calculate the value of the membership function of many variables μ(x) by formula (3) for each input value. In this case, since the indicators characterize the level of probability of occurrence of a risk event, then the term set of linguistic variables T is presented on a percentage numerical interval, to distinguish the terms [0; 100], where $t_1 \in [0; 25]$, $t_2 \in (25; 50]$, $t_3 \in (50; 75]$, $t_4 \in (75; 100]$.

$$\mu(x_1) = 1 - \sqrt{\frac{(50-100)^2}{(100)^2} + (0.6-1)^2} = 0.3597;$$

$\mu(x_2) = 0.5283$; $\mu(x_3) = 0.8$; $\mu(x_4) = 0.9$; $\mu(x_5) = 0.4901$; $\mu(x_6) = 0.7$; $\mu(x_7) = 0.9$.

2 step. Introduction of weights

Next, calculate the normalized weights by the formula (4): *v=(0.2; 0.18; 0.16; 0.1; 0.18; 0.1; 0.08).*

3 step. Derivation of an aggregate risk assessment

Let the expert estimate the average scenario, then calculate the convolution of assets of the airport by the formula (7): $R_3(S)$=0.6153.

4 step. Defuzzification data and decision-making

Based on the obtained aggregate risk assessment, we draw conclusions $R_3(S) = 0.6153 \in [0.4; 0.6)$ – AS: average level of UAV flight safety.

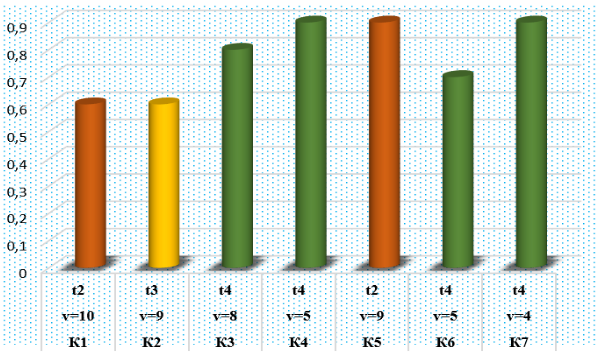

Fig. 1. Visualization of input data

As a result, on the test example we can conclude that the risk assessment of 0.6153 UAV flight for environmental research in the mountains, and this is the average level of flight safety for a particular mountain area and technical characteristics of UAV.

V. Results and Discussion

If we have clear quantitative information on the possibility of flying and conducting research, then on its basis, clear appropriate decisions are made. To obtain a quantitative assessment of risk, for example by meteorological conditions, you can use different systematic approaches to data analysis [15-17, 19]. In addition, to increase the validity of decisions, we propose to use the practical experience, skills and knowledge of the direct organizers of research and dispatchers of ground control point UAV.

In order to apply the developed fuzzy UAV flight risk assessment model to mountain environment research, it is necessary to adjust the fuzzification of input data and decision-making levels. These tasks are assigned to the practical experience of experts, or in this case to the controllers of the ground control point of UAV.

The constructed fuzzy model of UAV flight risk assessment based on risk-oriented factors has a number of advantages, namely: increases the objectivity of expert assessments using hybrid input data in the form of linguistic variables of the level of probability of risk occurrence and quantitative assessments control point in its conclusions; derives an aggregate UAV flight risk assessment based on the scenarios; displays a linguistic assessment of UAV flight safety. For the application of the developed model, a generalized step-by-step algorithm is proposed, which is easily implemented in the UAV flight decision support software.

The disadvantages of this approach include the use of different models of fuzzification of input data, which can lead to ambiguity of the final results.

The study developed a fuzzy UAV flight risk assessment model for environmental research in mountainous areas, taking into account risk-oriented factors influencing the implementation of the flight. As a result, we will obtain a quantitative assessment of flight risk and a linguistic interpretation of the level of safety of UAV flight, which will allow a reasonable approach to decision support. This is the first time the following results have been obtained:

- It is proposed to fuzzification the input data using the multidimensional membership function, which are presented in the form of linguistic estimates of the level of probability of occurrence of a risk event and quantitative estimates of the number of "reliability" of considerations of the ground control manager in his conclusions;
- A generalized step-by-step algorithm for obtaining a quantitative assessment of flight risk and linguistic interpretation of the level of safety of UAV flight;
- Experimental approbation and verification of the conducted research on test data of flight simulation of UAV is carried out.

The rationality of the obtained UAV flight risk assessment for the study of the environment in mountainous areas proves the advantages of the developed model. The reliability of the obtained results is ensured by the correct use of fuzzy set theory for the processing of expert knowledge, which is confirmed by the research results.

We see further research in the third stage of our study, namely: in the development of innovative software to support the decision to implement UAV flight, as well as testing and verification of the model and software on real experimental data. The study will be a useful tool to support safe decisions about UAV flight in different locations, and as a part of Aviation education within the Integrated laboratory for digital aviation education in selected subjects of flight training.

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REFERENCES

[1] International Civil Aviation Organization (ICAO) 10004, 2020 Edition, 2020-2022 Global Aviation Safety Plan, 2020, Available online: https://www.icao.int/meetings/anconf13/documents/doc_10004_gasp_2020_2022_edition.pdf.

[2] V. Polishchuk, A. Polishchuk, J. Jevčák, L. Choma, M. Kelemen jr, "Criteria for the information model for assessing the risks of unmanned aerial vehicle flights in environmental research on mountain terrain". *SGEM 2020 – XXth International Multidisciplinary Scientific GeoConference*, pp. 97-102, 16-25 August 2020, 2020.

[3] M. Kelemen, V. Polishchuk, B. Gavurová, R. Andoga, S. Szabo, W. Yang, J. Christodoulakis, M. Gera, J. Kozuba, P. Kaľavský, M. Antoško, "Educational Model for Evaluation of Airport NIS Security for Safe and Sustainable Air Transport", *Sustainability*, vol. 12, pp. 6352, 2020, [online] Available: https://doi.org/10.3390/su12166352

[4] R. Urban, M. Štroner, P. Blistan, Ľ. Kovanič, M. Patera, S. Jacko, I. Ďuriška, M. Kelemen, S. Szabo, "The Suitability of UAS for Mass Movement Monitoring Caused by Torrential Rainfall - A Study on the Talus Cones in the Alpine Terrain in High Tatras Slovakia", *ISPRS Int. J. Geo-Inf*, vol. 8, pp. 317, 2019.

[5] R. Salvini, G. Mastrorocco, G. Esposito, S. Di Bartolo, J. Coggan, C. Vanneschi, "Use of a remotely piloted aircraft system for hazard assessment in a rocky mining area (Lucca, Italy)", *Nat. Hazards Earth Syst. Sci.*, vol. 18, pp. 287-302, 2018.

[6] C.S. Watson, J.S. Kargel, B. Tiruwa, "UAV-Derived Himalayan Topography: Hazard Assessments and Comparison with Global DEM Products", *Drones*, vol. 3, pp. 18, 2019, [online] Available: https://doi.org/10.3390/drones3010018.

[7] M. M. Valero et al., "Thermal Infrared Video Stabilization for Aerial Monitoring of Active Wildfires", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 14, pp. 2817-2832, 2021, [online] Available: doi: 10.1109/JSTARS.2021.3059054.

[8] R.J. Garnica-Peña, I. Alcántara-Ayala, "The use of UAVs for landslide disaster risk research and disaster risk management: a literature review", *J. Mt. Sci.,* vol. 18, pp. 482-498, 2021, [online] Available: https://doi.org/10.1007/s11629-020-6467-7.

[9] Y. Karaca, M. Cicek, O. Tatli, A. Sahin, S. Pasli, M. F. Beser, S. Turedi, "The potential use of unmanned aircraft systems (drones) in mountain search and rescue operations", *American Journal of Emergency Medicine*, vol. 36, pp. 583-588, 2018.

[10] D. Giordan, M.S. Adams, I. Aicardi et al, "The use of unmanned aerial vehicles (UAVs) for engineering geology applications", *Bull Eng Geol Environ*, vol. 79, pp. 3437-3481, 2020.

[11] S. Schopferer, S. Benders, "Minimum-risk path planning for long-range and low-altitude flights of autonomous unmanned aircraft", *AIAA Scitech 2020 Forum*, pp. 0137, 2020.

[12] R. Rozenberg et al., "Information Model for Evaluation and Selection of Instructor Pilots for Smart City Urban Air Mobility," *2020 5th International Conference on Smart and Sustainable Technologies (SpliTech)*, Split, Croatia, 2020, pp. 1-6.

[13] M. Kelemen et al., "Municipality Management and Model of Evaluation and Selection of the Expert Group Members for Smart City Transportation and Mobility including UAV/UAS," *2020 5th International Conference on Smart and Sustainable Technologies (SpliTech)*, Split, Croatia, 2020, pp. 1-6, doi: 10.23919/SpliTech49282.2020.9243705.

[14] M. Malyar, Modeli i metody bahatokryterialnoho obmezheno-ratsionalnoho vyboru: Monograph, Uzhgorod: RA «AUTDOR-SHARK», 2016.

[15] YU.P. Zaychenko, Nechetkiye modeli i metody v intellektualnykh sistemakh: navchalny posibnyk, Kiyev: Slovo, 2008.

[16] V. Polishchuk, M. Malyar, M. Kelemen, A. Polishchuk, "The Technology for Determining the Level of Process Control in Complex Systems", *2020 VII International conference Information Technology and Interactions (IT&I-2020), CEUR Workshop Proceedings*, Vol. 2845, pp. 138-148, 2-3 December 2020, 2020, doi: http://ceur-ws.org/Vol-2845/Paper_14.pdf.

[17] V. Polishchuk, M. Kelemen, B. Gavurová, C. Varotsos, R. Andoga, M. Gera, J. Christodoulakis, R. Soušek, J. Kozuba, P. Blišťan, S. Szabo Jr., "A Fuzzy Model of Risk Assessment for Environmental Start-up Projects in the Air Transport Sector", Int. J. Environ. Res. Public Health, vol. 16, pp. 3573, 2019, [online] Available: https://doi.org/10.3390/ijerph16193573.

[18] V. Kotsovsky, A. Batyuk, Representational capabilities and learning of bithreshold neural networks, In: Babichev, S. et al. (eds.) Advances in Intelligent Systems and Computing, vol. 1246. Springer, Cham, 2021, pp. 499–514.

[19] M. Zhurovs′kyy, N. Pankratova, Osnovy systemnoho analizu, Kyyiv: VNV, 2007.