Chapter

ICAO Risk Tolerability Solution via Complex Indicators of Air Traffic Control Students' Attitude to Risk

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Abstract

The solution of the ICAO risk tolerability is proposed via complex indicators of air traffic control students' attitude to risk. Physically tangible rates and characteristics are used to determine air traffic control students' attitude to risk levels during flight separation minima violation. The following features of human factors expression are taken as corresponding indicators: main decision-making dominants, aspiration levels, and parameters of the fuzzy risk estimates. The final solution is received with the help of a multiplicative approach. Indicators developed in the paper are proposed to be received with special survey procedure and further results processing and normalization. The explained method is applicable for both acting air traffic controllers and students of the corresponding educational majors.

Keywords: human factor, risk estimation, air traffic control, separation minima, aspiration level, main-decision making dominant, fuzzy estimates, risk tolerability solution

1. Introduction

Professional activity of "frontline" air operators (flight crew and air traffic controllers) can be considered a continuous decision-making chain in risk circumstances. This activity is part of the human factor, which is the main reason for air accidents for the last decades according to the statistics [1, 2]. Detrimental impact of the risk perception on flight safety is relevant for civil aviation. This is especially urgent for a complex system "flight crew—aircraft—environment—air traffic control authority" [3–5].

Results of researches dedicated to the development and operation of air transport management (ATM) system show that sufficient flight safety level support is impossible without efficient, proactive risk management activities. In turn, these activities are an integral component of the system and entirely correspond to the International Civil Aviation Organization (ICAO) safety paradigm.

According to the ICAO definition, flight safety is "the state, in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level." Thus, it is necessary to take into account risk estimates for the proper support of flight safety. Considering the definitions by Eurocontrol, International Civil Aviation Organization (ICAO), and other sources [6–10], let us regard risk as a probability of undesirable situation with harmful consequences. Its "severity" part can be determined using various methods, including the qualimetrical ones. They allow forecasting hazardous situations and performing necessary activities by the management and operator of the air transport system. It contributes to accident prevention and risk reduction.

Risk management-related tasks should be resolved. In order to do this, some necessary qualimetrical steps should be carried out. They should include the evaluation of quality-quantity indicators of the control process. This issue is relevant and complex for civil aviation. Indeed, hazards tend to accumulate during air transport system operation. Taking into account numerous objective and subjective factors, this might result in the so-called "factor resonance" phenomenon [11].

2. Risk tolerability

Generalizing worldwide experience of flight safety management, ICAO proposed to estimate civil aviation threats with special risk tolerability distribution [7]. It is composed of two aviation accidents parameters: likelihood and severity. All their possible combinations were considered. ICAO divided obtained results into three groups: Intolerable, tolerable, and acceptable (**Figure 1**).

There are five qualitative levels of the air accident likelihood and severity proposed by ICAO. They are recommended for risk estimation and combined into the safety risk matrix. These levels can be described using the terms of fuzzy mathematics taken as corresponding fuzzy variables $T(S)$ and $T(L)$ [12, 13]:

$$T(S) = R_C + R_H + R_{Mj} + R_{Mn} + R_N; \quad (1)$$

$$T(L) = R_F + R_O + R_R + R_I + R_{EI}; \quad (2)$$

where fuzzy variables' terms are R_C—catastrophic, R_H—hazardous, R_{Mj}—major, R_{Mn}—minor, R_N—negligible, R_F—frequent, R_O—occasional, R_R—remote, R_I—improbable, and R_{EI}—extremely improbable. Risk cases distribution across all possible likelihood and severity combinations is shown in **Table 1**.

Using the ICAO flight safety management recommendations, the US Federal Aviation Administration published circular with their own safety risk matrix. Combinations of severity and likelihood explained there have 62.5% of partially or totally acceptable levels [14]. However, they use four levels for both severity and likelihood. Moreover, the "acceptable risk level" is determined as a flexible value, which depends on the pilot's particular opinion.

Risk estimation proposed by Eurocontrol is partial and concerns severity only [6]. Also, their recommendations delegate calculation of risk distribution

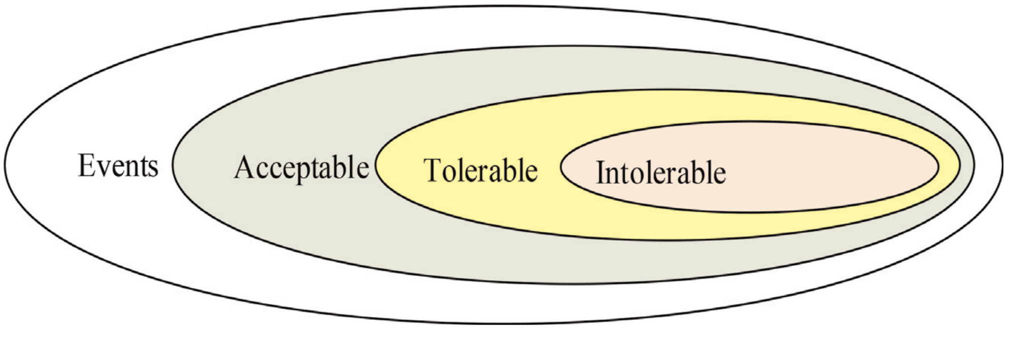

Figure 1.
Risk cases distribution.

combinations to the national authorities. Another risk matrix is proposed by the Korea Advanced Institute of Science (KAIS), Hongneung Campus, Seoul [15]. Some of these examples use four and five risk levels, while ICAO sticks to the three ones mentioned earlier. To keep up with ICAO, it's definitions are used; and, therefore, 4-rate and 5-rate cases falls out of the analysis scope.

Providing general comments on risk tolerability, ICAO unfortunately gives no exact values. That is why various methods should be used to resolve risk tolerability distribution. Results of this kind can be implemented to enhance ATC learning process, to influence aircraft separation minima changes, to improve rules and instructions, etc.

The priority arrangement method (PRM) is the first one. It applies the normalized significance coefficient for each term of both fuzzy variables. Unfortunately, this led to a significant decrease in the number of generally acceptable cases that is unacceptable from the common-sense point of view [16]. Another method used for the same purpose is Harrington desirability function [17]. The results for all the mentioned approaches are shown in **Table 2**.

Another crucial point is that risk tolerability distribution solution should be performed with tangible and clear indicators and parameters. The "frontline" air operators should be primarily familiar with them. Such clarification problem is resolved with application of such ICAO safety concept components as the use of sound SOPs, hazard sources determination, risk factors control, personnel attitude to hazardous actions and conditions, etc. [18]. Considering the "attitude to risky actions or conditions" as the leading inbound marker to the problem, it is regarded as an explanatory link for flight safety within the human factor.

Risk cases indicators	Risk level description
5A, 5B, 5C, 4A, 4B, 3A	Intolerable
5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Tolerable
3E, 2D, 2E, 1B, 1C, 1D, 1E	Acceptable

Table 1.
ICAO risks cases [7].

Approach	Risk level (%)		
	Intolerable	Tolerable	Acceptable
ICAO proposal	24	44	32
FAA proposal	18.75	18.75	62.5
Harrington coefficients	40	36	24
PRM iteration 1	28	40	32
PRM iteration 2	68	20	12
PRM iteration 3	76	12	12
PRM iteration 4	76	20	4
PRM iteration 5	84	12	4
PRM iteration 6	88	8	4
PRM iteration 10	88	8	4

Table 2.
Risk tolerability distributions.

"Frontline" air operators' professional activity is a continuous chain of decisions generated and implemented in apparent and latent forms. It is also influenced by multiple factors of stochastic and deterministic nature. Thus, it is possible to research the mentioned above attitude through the human factor indicators that influence decision making under risk circumstances:

- Main decision-making dominants;
- Aspiration levels;
- Fuzzy risk estimates.

Typical values of these indicators should be used to resolve risk tolerability distribution. It is worth mentioning that there are no similar studies of risk tolerability distribution resolution for presented rates.

Let us examine these indicators and their roles in more details. Researches performed so far deal with the risk of flight separation minima violation set by ICAO for the horizontal plane as at 2014.

3. Case study conditions

All methods proposed later on were implemented in the case study, which includes survey and data processing. In the performed survey, 132 air traffic controller students of fourth to fifth years of study from National Aviation University (Kyiv, Ukraine) and Kirovohrad Flight Academy (Kropyvnytskyi, Ukraine) were involved. By the time of the survey, all of them had completed at least 1 year of learning with more than 100 hours at ATC simulation facilities. In the survey, 11 flight separation minima were proposed including 8 km (1 minimum), 10 km (4 minima), 12 km (1 minimum), 20 km (4 minima), and 30 km (1 minimum). All minima were proposed to the students one by one during the survey.

4. Main decision-making dominants

Main decision-making dominants [19–30] are parameters of human factor influence on decision making. They describe the attitude of "frontline" air operators to risk: whether the operator is inclined, not inclined, or indifferent to risky behavior. They also characterize motivation to achieve success or avoid failure. Dominants are found from utility estimation functions $f_{UF}(L)$ received from the distances between two aircraft within violated separation minimum.

In the simplest cases, the form of the utility function chart can be used to define the main decision-making dominant. However, for more detailed analysis, risk premium (RP) concept is introduced [31]. Risk premium is the difference between expected lottery reward, and it is determined equivalent.

The classical approach uses only one point $L_{0.5}$ for dominant determination:

$$RP = \overline{L} - L_{0.5} \begin{cases} < 0 & - \quad \textit{inclined to risk} \\ > 0 & - \quad \textit{not inclined to risk}\,, \\ = 0 & - \quad \textit{indifferent to risk} \end{cases} \tag{3}$$

where $\overline{L}-$ is an expected lottery point:

$$\overline{L} = 0.5 \cdot (L_0 + L_1) = 0.5 \cdot (0 + L_{norm}) = 0.5 \cdot L_{norm}. \tag{4}$$

Use of Eq. (4) for dominant determination makes results a bit rough. It can be show by the example, when $\overline{L} = L_{0.5}$ (**Figure 2**, blue line). In this case, the respondent demonstrates an indifferent attitude to risk. But an example when this conclusion is wrong can be easily proposed (**Figure 2**, red line). It is achieved with introducing of two more points in the dominant analysis.

Five points are used instead of three to increase accuracy. The analysis of the points can be performed using coordinates proportion method [20]. According to this method, the sum of coordinates $\sum y$, which is equal to 2.5L, corresponds to the linear utility function of the respondent who is indifferent to risk. Thus, it is enough to compare coordinates of the sum of five points with 2.5L. Risk-indifferent participants have $\sum y = 2.5L$, the risk inclined ones have $\sum y > 2.5L$, and the risk non-inclined respondents have $\sum y < 2.5L$.

The key distances, taken as the points, are 0 km, distance for ¼ of utility, distance for half of the utility, distance for ¾ of utility, and full separation minimum (L_0, $L_{0.25}$, $L_{0.5}$, $L_{0.75}$, L_{norm}). Such distances are chosen to support utility lotteries solution. Each distance possesses a particular utility $u(L)$. Border points obviously have utilities equal to 0 and 1. Intermediate points have utility values equal to 0.25, 0.5, and 0.75, correspondingly:

$$\begin{gathered} u(L=0) = f_{UF}(L=0) = 0; \quad u(L_{0.25}) = f_{UF}(L_{0.25}) = 0.25; \\ u(L_{0.5}) = f_{UF}(L_{0.5}) = 0.5; \quad u(L_{0.75}) = f_{UF}(L_{0.75}) = 0.75; \\ u(L_1 = L_{norm}) = f_{UF}(L_1 = L_{norm}) = 1. \end{gathered} \tag{5}$$

All intermediate distances are found with the help of lotteries. These lotteries are commonly implemented in economic proceedings [32]. However, they were applied for hardware performance as well [19], what makes them applicable for aviation risks assessment. The method of two-level lotteries application in aviation risk evaluation is already explained in details earlier [20–30].

Lottery method is applied three times to get three lottery equivalents. Here, a lottery equivalent is a result that represents the distance between two aircraft. This distance is such that operator does not care whether to get it with 100% probability or to participate in the lottery. In other words, it is used to find the distance of lottery equivalent $L_{0.5}$ with the utility of 0.5. The lottery has 50% of receiving any

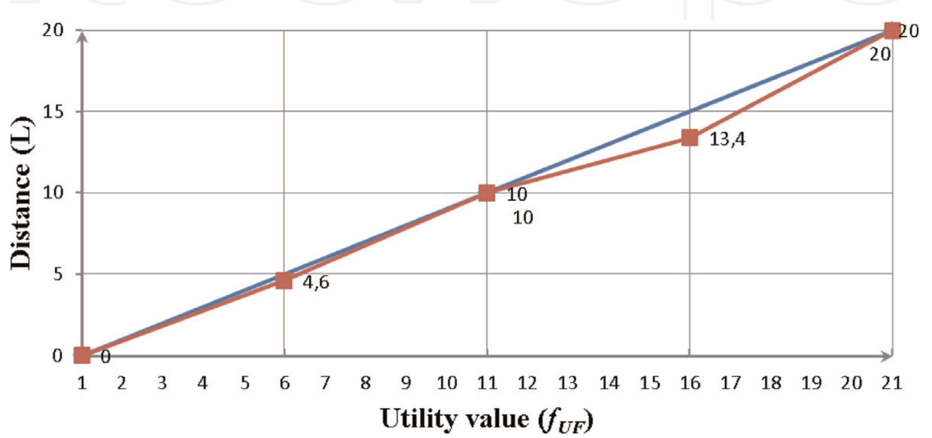

Figure 2.
Rough estimation example leading to wrong conclusion for L = 20 km. Blue line—rough estimate; red line—improved estimate.

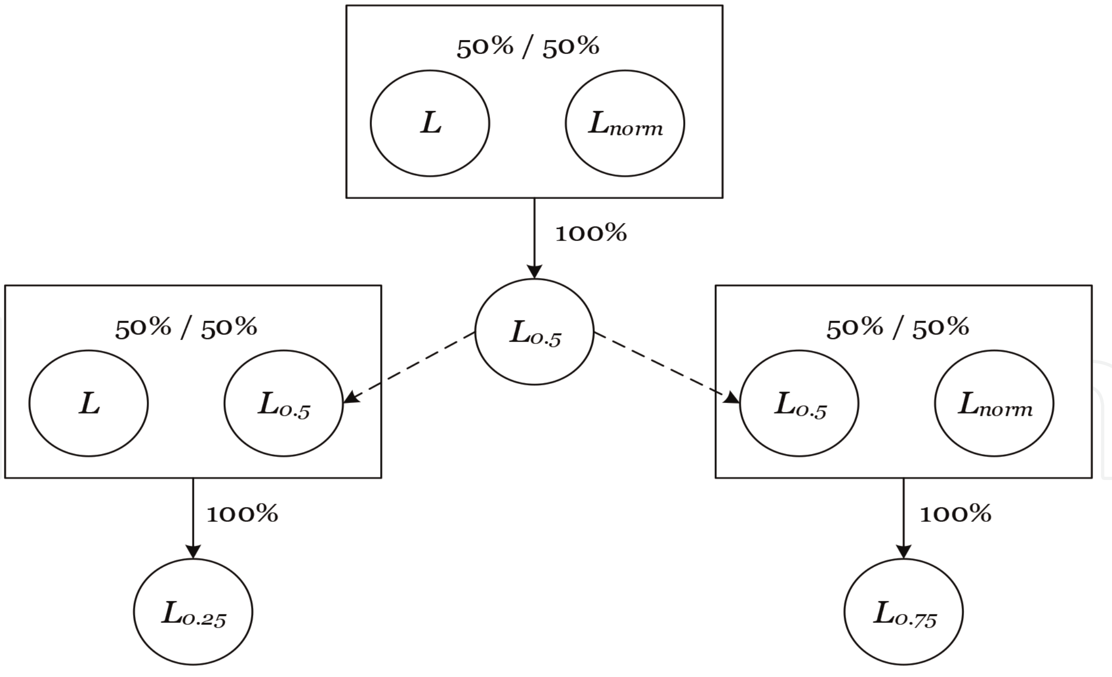

Figure 3.
Lotteries used to determine utility function points for flight separation minima.

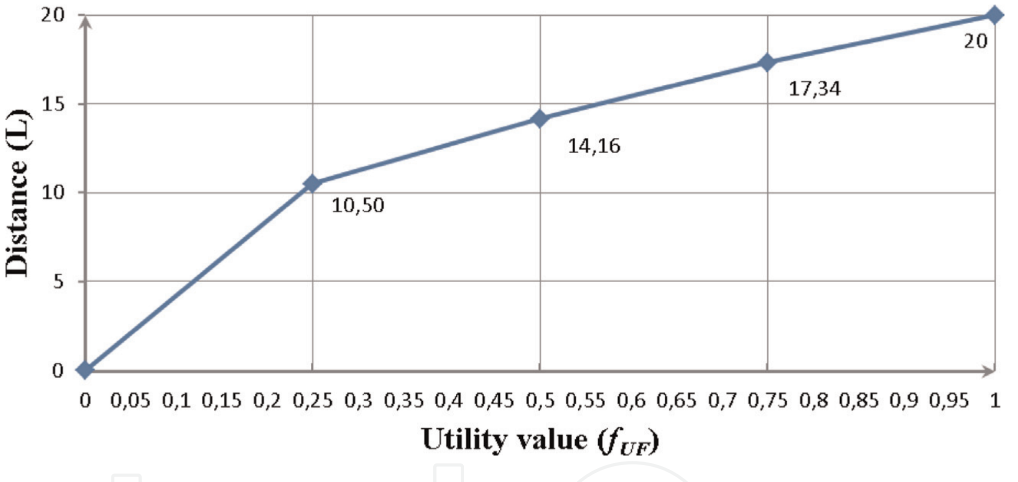

Figure 4.
Generalized utility estimate function for all participants with the flight separation minimum $L = 20$ *km.*

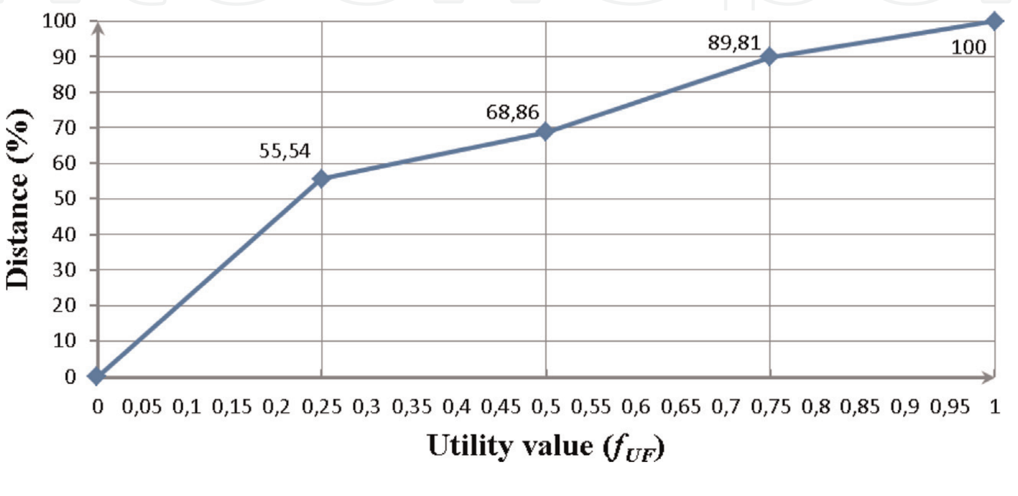

Figure 5.
Normalized utility estimate function for all participants and all flight separation minima.

marginal results. For the lottery of the first level, these results are 0 km and full flight separation minimum.

The first received lottery equivalent is used to find two more lottery equivalents for $L_{0.75}$ and $L_{0.25}$ (**Figure 3**). Considering two initial points and three point received from lotteries, it is possible to build the desired utility estimate function.

The example of generalized utility estimate function for all participants plotted for $L = 20\ \ km$ is given in **Figure 4**.

Normalized utility estimate function for all participants concerning all proposed minima is given in **Figure 5**.

Figures 4 and **5** show that utility rise in a non-linear way. Utility function data are taken from case study survey. In both graphs, a fundamental understanding of risk for all involved ATC students concerning single $L = 20\ \ km$ separation minimum (**Figure 4**) and all mentioned minima taken together (**Figure 5**) is presented. According to the graph points, it can be stated that, in general, ATC students possesses non-inclined to risk behavior.

5. Aspiration level

Aspiration level is one of the main psychological features and participants' typical peculiarities, fundamental for personality. It is recommended to be determined during the medical investigation of air accident [33]. Basically, aspiration level is the stable characteristic of an identity, which is used: (a) for defining the complexity level of tasks wanted to be resolved, (b) for the target selection of further actions depending on the previous success/failure, and (c) for determining the desired self-image. Aspiration level demonstrates the correspondence between personal goals and capabilities. Thus, aviation operators with high aspiration level are characterized by high confidence level, persistence, high productivity, and healthy criticism in achievements estimation [34, 35].

Given researches are related to the of human factor expression qualimetry during flight separation minima violation. Considering recommendations of the proceedings [5], hereafter, the aspiration level is defined as a point of distance L^* on the flight separation minimum. The L^* point corresponds to the highest utility increase from the air traffic controller's point of view. In other words, it corresponds to ATC operator's highest performance during support of proper flight safety level at given distance between two aircraft. The proceedings [16, 36, 37] allow plotting and analyzing utility chart by a formally unlimited number of points for open decision-making task.

Since the aspiration level L_{AL} is the relatively stable indicator of personal air traffic controller commitments [16, 38–41], then $L_{AL} = L$ if and only if.

$$\begin{cases} \Delta f_{UF}(L) = f_{UF}(L_r) - f_{UF}(L_{r-1}) > f_{UF}(L_i) - f_{UF}(L_{i-1}); \\ i = \overline{2, (r-1)}, \end{cases} \tag{6}$$

or if

$$\begin{cases} \Delta f_{UF}(L) = f_{UF}(L_r) - f_{UF}(L_{r-1}) \Rightarrow \max; \\ f_{UF}(L_r) > 0. \end{cases} \tag{7}$$

The overall contribution from this utility function includes three more reference points. They are L^-, which corresponds to maximum utility increase in lower semi plane $(-100;\,0)$, L^0, which corresponds to distance with 0 utility for $(-100;\,100)$

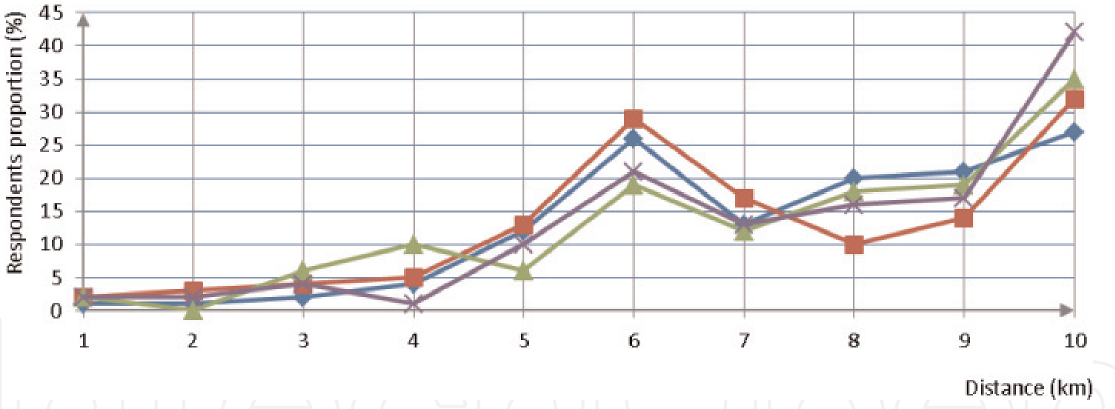

Figure 6.
The aspiration levels distribution of the respondents for four flight separation minima of the cross-aircraft aircraft $L = 10\ km$. Distances as at 2014. Red line—under IFR (instrument flight rules) procedure with continuous radar monitoring in the approach area APP (local ATC) (TMA (terminal control area)) using ATC automated system except approach segment; Blue line—at take-off phase (within control zone (CTR (control zone) at altitudes 1700 m and below) when medium aircraft follows heavy; Green line—for lateral separation for the IFR flights under continuous radar monitoring when crossing the level occupied by the same direction traffic in ACC (general ATC) (CTA (control area)) and APP (TMA) at the moment of crossing on conditions that no tracks converging; Purple line—under IFR procedure with continuous radar monitoring when crossing the same direction level occupied by another aircraft in approach area APP (TMA) using ATC automated system at the moment of crossing on conditions that no tracks converging.

scale, and L^+, which corresponds to the maximum utility increase in top semi plane (0; 100).

After data analysis, a series of charts for all 11 separation minima were plotted. The examples of these charts are presented in **Figure 6**. Each chart here represents a single aspiration indicator distribution for one of four $L = 10\ km$ minima. Each of the presented four plots shows how many participants consider each particular distance between 0 km and separation minimum as delivering maximum utility. In other words, every plot shows aspiration level distribution for all respondents. For all the taken minima, the distance chosen most often is 10 km, which is the separation minimum itself. However, many ATC students choose other distances to provide maximum utility growth.

Interestingly, all the taken minima have peak point close to the middle of the separation minimum range. In **Figure 6**, such middle peaks coincide for all $L = 10\ km$ separation minima. The same effect is observed for the group of $L = 20\ km$ separation minima as well.

6. Fuzzy estimates

Main decision-making dominants and aspiration levels do not cover the whole totality of human factors expression during flight separation minima violation. The experience of earlier researches witnesses that the human factor qualimetry can be significantly improved by fuzzy models of risk level estimation [42–50]. These models implementation conforms to the human mental process property of providing qualitative estimates rather than quantitative.

Considering all mentioned above and applying Miller's "magic number" [51], the following risk severity scale can be presented as the fuzzy variable T:

$$T = \tilde{R}_C + \tilde{R}_{VB} + \tilde{R}_B + \tilde{R}_{AV} + \tilde{R}_S + \tilde{R}_{VS} + \tilde{R}_D. \tag{8}$$

where $\tilde{R}_C$—critical, $\tilde{R}_{VB}$—very big, $\tilde{R}_B$—big, $\tilde{R}_{AV}$—average, $\tilde{R}_S$—small, $\tilde{R}_{VS}$—very small, and $\tilde{R}_D$—disappearing.

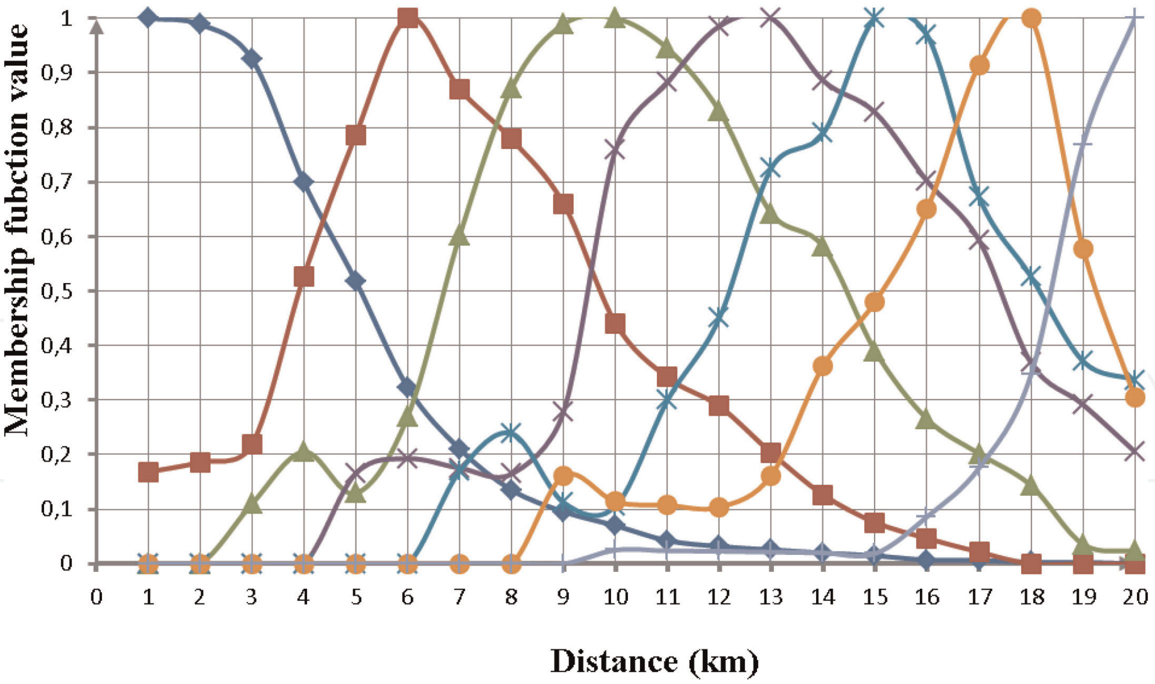

Figure 7.
The values of the membership function for "risk severity" fuzzy variable terms: Blue—"Critical," red—"Very big," green—"Big," purple—"Average," light blue—"Small," orange—"Very small," and teal—"Disappearing."

Using the proposed scale (Eq. (8)), air traffic control students as respondents expressed their opinions about hazard severity for all distances between two aircraft during flight separation minima violation [45, 52]. Their answers gave data for the fuzzy variable membership function of "risk severity" [53, 54]. After the initial data are collected, they are normalized using the "supportive matrix" method [55]. The final values are used to plot the family of membership functions charts for all terms of "risk severity" fuzzy variable (**Figure 7**).

Starting from the left side, each line represents a separate fuzzy variable term of the membership function value (catastrophic, very big, big, average, small, very small, and negligible) concerning every possible distance between two aircraft.

Every line in **Figure 7** shows the integral opinion of cross-aircraft distance categorized as one of the seven severity levels. For example, the distance of 6 km is considered to have a "very big" severity level with the membership value of 1. At the same time, the nature of fuzzy values also possesses the severity of "catastrophic," "big," and "average" levels with the correspondent membership values. Such plot allows finding aggregated ATC students' opinion about the distances belonging to the particular severity levels.

Since one of the main requirements is to be as close as possible to the ICAO terms, the number of given terms should be reduced. It is performed by the removal of the modifier "very" [9, 51, 55]. After all, the seven use terms were reduced to five in the following way:

$$\begin{matrix} \tilde{R}_C & \tilde{R}_{VB} \cup \tilde{R}_B & \tilde{R}_{AV} & \tilde{R}_S \cup \tilde{R}_{VS} & \tilde{R}_D \\ \Downarrow & \Downarrow & \Downarrow & \Downarrow & \Downarrow \\ \tilde{R}_C & \tilde{R}_B & \tilde{R}_{AV} & \tilde{R}_S & \tilde{R}_D \end{matrix}. \quad (9)$$

7. Aggregation

Since three different parameters are used to define the opinions of ATC students about risk, it would be convenient to combine them into one single indicator. Such an indicator should include all three parameters with reasonable proportions. In current research, the widely applicable aggregation function is taken [9]:

$$f = \left(\frac{1}{k} \sum_{i=1}^{k} \alpha_i \times R_i^p \right)^{\frac{1}{p}}, \tag{10}$$

where p is conditional compromise coefficient which is used to define the acceptable compensation rate of small values with big ones, k is number of risk indicators (in current case $k = 3$), R_i is an indicator, determined by risk level, and α is a weight coefficient. For main decision-making dominant, R_D is used, R_{AL} is used for aspiration level, and R_F for fuzzy estimates. Since there is no preliminary information about their significance, they are considered to be equally important. Taking into account the same assumption, $p \to 0$ for the "careful" aggregation policy and thus:

$$\phi = \prod_{i=1}^{k} R_i. \tag{11}$$

The multiplicative approach is clear, applied with ease, and has an extensive application history among technical and humanistic systems research [51, 55–59]. However, since data should be normalized to the [0, 1] range, it should be changed in the following way:

$$\phi = \sqrt[k]{\prod_{i=1}^{k} R_i}. \tag{12}$$

Thus, for a single flight separation minimum, aggregated estimate takes the following form:

$$R = \sqrt[3]{R_D \cdot R_{AL} \cdot R_F} = \sqrt[3]{\frac{L_D}{L_{norm}} \cdot \frac{L_{AL}}{L_{norm}} \cdot \frac{L_F}{L_{norm}}}. \tag{13}$$

Here, (L_D, L_{AL}, L_F) are generalized and normalized distances found for main decision-making dominant, aspiration level, and fuzzy estimates, correspondingly. The L_{norm} distance stands for the separation minimum distance taken for reference.

The last thing to do is to select the proper key points of all three methods. During the detailed analysis, the following rules were reached:

- All 11 flight separation minima should be taken into account;
- Dominants should be used for all risk inclination categories;
- Lottery equivalent in use is 0.75 as it strongly correlates with the aspiration level;
- The aspiration level itself is taken for all minima;
- A fuzzy estimate is considered as the severity level changing from minor to major in the ICAO concept (from average to small in authors' terms).

These rules allowed to receive separate formulas for each risk level indicator and the general formula for integral calculations. The correspondent results of

No	Separation minimum	Particular methods indicators			Integral indicator R
		R_D	R_{AL}	R_F	
1	L = 8 km	0.74	0.77	0.74	0.75
2	L = 10 km	0.78	0.75	0.66	0.73
3		0.78	0.72	0.66	0.72
4		0.79	0.75	0.70	0.75
5		0.80	0.77	0.69	0.75
Generalize within distance		0.79	0.75	0.68	0.74
6	L = 12 km	0.75	0.72	0.76	0.74
7	L = 20 km	0.70	0.68	0.60	0.66
8		0.65	0.75	0.73	0.71
9		0.72	0.73	0.62	0.69
10		0.70	0.71	0.69	0.70
Generalize within distance		0.69	0.71	0.66	0.69
11	L = 30 km	0.68	0.73	0.71	0.71
Final estimate		0.73	0.74	0.71	0.73

Table 3.
Aggregated indicators for risk level estimation (yellow cells designate final value for a single separation minimum or generalized minima with the same distances).

generalized and aggregated indicators overall calculations are presented in **Table 3**. Given results show that air traffic controllers, in general, consider distances more than 0.73 of flight separation minima as acceptable.

Table 3 shows the final point, which may be called severity separator. It can be found in the right bottom cell. In the opinion of ATC students, all distances to the left from this point are more likely to be risky, and vice versa, all distances to the right from this point are more likely to be riskless. Such a result can be also considered as an integral reserved value for flight separation minima.

8. Risk tolerability distribution solution

To resolve the ICAO risk tolerability distribution, the following approach was applied. Since there are five levels of severity, four key points are required.

- Concerning main decision-making dominants, three lottery key points were considered as an intermediary between the severity levels. The last fourth point was taken as flight separation minimum distance.
- Concerning aspiration levels, three key utility points were used with the flight separation minimum distance as well.
- Concerning fuzzy estimates, the reduced intersection points were used, as shown in Eq. (9).

The final results with all three presented methods are presented in **Table 4**. Here, R_C—catastrophic risk level, R_H—hazardous risk level, R_{Mj}—major risk level, R_{Mn}—minor risk level, R_N—negligible risk level, L_C—distance equivalent to catastrophic risk level, L_H—distance equivalent to hazardous risk level, L_{Mj}—distance

Risk levels		Models in use		
		Dominants	Aspiration levels	Fuzzy estimates
Unacceptable	R_C	$L_C < L_{0.25} \Leftrightarrow$ $\Leftrightarrow L_C < 0.31$	$L_C < L^- \Leftrightarrow$ $\Leftrightarrow L_C < 0.46$	$0 < L_C < \tilde{L}_C \Leftrightarrow$ $\Leftrightarrow 0 < L_C < 0.42$
	R_H	$L_{0.25} < L_H < L_{0.5} \Leftrightarrow$ $\Leftrightarrow 0.31 < L_H < 0.53$	$L^- < L_H < L^0 \Leftrightarrow$ $\Leftrightarrow 0.46 < L_H < 0.65$	$\tilde{L}_C < L_H < \tilde{L}_B \Leftrightarrow$ $\Leftrightarrow 0.42 < L_H < 0.56$
	R_{Mj}	$L_{0.5} < L_{Mj} < L_{0.75} \Leftrightarrow$ $\Leftrightarrow 0.53 < L_{Mj} < 0.73$	$L^0 < L_{Mj} < L^* \Leftrightarrow$ $\Leftrightarrow 0.65 < L_{Mj} < 0.74$	$\tilde{L}_B < L_{Mj} < \tilde{L}_{AV} \Leftrightarrow$ $\Leftrightarrow 0.56 < L_{Mj} < 0.71$
Acceptable	R_{Mn}	$L_{0.75} \le L_{Mn} < L_{norm} \Leftrightarrow$ $\Leftrightarrow 0.73 < L_{Mn} < L_{norm}$	$L^* < L_{Mn} < L_{norm} \Leftrightarrow$ $\Leftrightarrow 0.74 < L_{Mn} < L_{norm}$	$\tilde{L}_{AV} < L_{Mn} < \tilde{L}_S \Leftrightarrow$ $\Leftrightarrow 0.71 < L_{Mn} < 0.83$
	R_N	$L_N \ge L_{norm}$	$L_N \ge L_{norm}$	$L_N \ge 0.83$

Table 4.
Partial solutions of ICAO risk tolerability distribution for flight separation minima.

Risk levels		Integral estimates
Unacceptable	Catastrophic	$L_C < 0.39$
	Hazardous	$0.39 \le L_H < 0.58$
	Major	$0.58 \le L_{Mj} < 0.73$
Acceptable	Minor	$0.73 \le L_{Mn} < 0.94$
	Negligible	$L_N \ge 0.94$

Table 5.
The integral solution of ICAO risk tolerability distribution with risk estimates.

equivalent to major risk level, L_{Mn}—distance equivalent to minor risk level, L_N—distance equivalent to negligible risk level, $L_{0.25}$—distance equivalent to 0.25 lottery determinant, $L_{0.5}$—distance equivalent to 0.5 lottery determinant, $L_{0.75}$—distance equivalent to 0.75 lottery determinant, L^-, L^0, and L^+ were explained earlier, $\tilde{L}_C$—distance where "critical" term ends, $\tilde{L}_B$—distance where "big" term ends, $\tilde{L}_{AV}$—distance where "average" term ends, and $\tilde{L}_S$—distance where "small" term ends.

Finally, the application of a multiplicative approach allows to resolve the ICAO risk tolerability distribution (**Table 5**) with integral estimates.

9. Conclusions

It is possible to make general conclusions based on the presented scientific results. These conclusions concern the development of a new methodology. It is dedicated to the qualimetry of human factor regularities expression during the decision making in aeronautical systems. The ICAO recommendations were taken into account during the correspondent indicators development. They were implemented by the composition of fuzzy models applied to air traffic control students' attitude to flight separation minima violation in a horizontal plane. Other components of such attitude include well-grounded key points of utility estimate functions for the mentioned minima continuum plotted within formally closed and open decision-making tasks. The first group of points is used to find respondents' main decision-making dominants (inclination, indifference, and non-inclination to risk). The second group of points is used to find aspiration levels that correctly characterize respondents' self-image.

Important scientific results include:

1. For the first time, the multiplicative approach is grounded and implemented to determine the integral estimate of air traffic control students' attitude both to sole flight separation minimum and minima totality. The correspondent cent is equal to 0.73 of flight separation minima.

2. The new method of main decision-making dominant determination is proposed. It differs from the widely known one by more key points being used and a novel algorithm submitted for their analysis.

3. The results of the main decision-making dominants analysis show that non-inclination is a major attitude among air traffic control students. It allows changing the professional education programs, taking into account the received results.

4. Especially important feature of the received results is their proactivity. It will enable preventing potentially harmful consequences of air traffic controllers' work by implementing personalized training on various simulators.

All the results form strong premises for further researches, which should be performed in the following areas:

a. The study of decision-making indicators, taking into account age, academic performance, and other factors;

b. The analysis of the mentioned indicators dynamics during the whole professional activity period of air traffic control personnel;

c. The complex research of the proposed indicators for three dimensions with space utility functions plot and integral indicators estimation for such conditions.

It should be mentioned that further research areas are not limited to the proposed ones but merely demonstrate opinion on primaries.

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References

[1] Human Factors Guidelines for Safety Audits Manual: Doc. ICAO 9806-AN/763; Montréal, Quebec, Canada. 2002. p. 138

[2] Boeing Commercial Airplanes. Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959–2017. 2017. Available from: http://www.boeing.com/news/techissues/pdf/statsum.pdf [Accessed: 27 June 2019]

[3] Human Factors Training Manual. 1st edn. Doc. ICAO 9683-AN/950; Montréal, Quebec, Canada. 1998. p. 302

[4] Human Factors Digest No. 7, Investigation of Human Factors in Accidents and Incidents. ICAO Circular 240-AN/144; Montréal, Quebec, Canada. 1993. p. 66

[5] Reva AN, Tumyshev KM, Bek-muhambetov AA. Human Factor and Flight Safety (Proactive Influence Research); Almaty. 2006. p. 242

[6] Eurocontrol Safety Regulatory Requirement. ESARR 4. Risk Assessment and Mitigation in ATM. 2001. p. 22

[7] Safety Management Manual (SMM): Doc. 9859, AN/474. 4th edn; Montréal, Quebec, Canada. 2018. p. 182

[8] Karmaleev BA. Risks in flight work management, Saint Petersburg. 2010. p. 82

[9] Kharchenko VP, Shmelyova TF, Sikirda YV. Decision Taking by Airnautical System Operator; Kirovohrad. 2012. 292 p

[10] Slobodskoy AL. Risk in Personnel Management; Saint Petersburg. 2011. p. 155

[11] Polojevets AA, Korneev SV. Experimental research of the first signs of factor overlays and factor resonans during the flights in civil aviation companies (1985–2005). Cybernetics and Computer Engineering. 2009;**157**:36-43

[12] Reva OM, Borsuk SP, Shulgin VA. Modern Problems of Human Factor in Aviation; Kyiv. 2018. p. 124

[13] Reva OM, Borsuk SP, Shulgin VA, et al. "Front Line" Aviation Operators Attitude to the Hazardous Actions or Conditions of Professional Activity as Main Actor of Flight Safety Provision. MINTT-2016; 24-26 May 2016; Kherson. 2016. pp. 90-97

[14] Risk Management Handbook. U.S. Department of Transportation Federal Aviation Administration. 2016. p. 112

[15] Korea Advanced Institute of Science and Technology. 2019. Available from: https://true.kaist.ac.kr/risk-manageme nt–evaluation.html [Accessed: June 25, 2019]

[16] Reva O, Borsuk S. Kharchenko multiplication of air accidents frequency and Hazard desirability coefficients for ICAO safety risk tolerability matrix solution. Logistics and Transport. 2015; **1**(25):63-69

[17] Harrington EC. Desirability function. Industrial Quality Control. 1965;**21**(10):494-498

[18] Reva OM, Borsuk SP, Bala MM, Peyman MS. New approach to determination of Main solution taking dominant of air traffic controller during flight level norms violation. In: Advances in Human Aspects of Transportation Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation; 27-31 July 2016. Florida, USA: Walt Disney World; 2016. pp. 137-147

[19] Myryumin SM. Utility Function Plot for Computing Devices Properties Estimation. Documents Exchange. Available from: https://docplayer.ru/36882468-Postroenie-funkcii-polez nosti-dlya-ocenki-sredstv-vychislite lnoy-tehniki-s-m-muryumin.html [Accessed: 27 June 2019]

[20] Borsuk SP. Determination of air traffic control students main behavior dominant in separation norms violation. Science-Based Technologies. 2015;**3**(27): 261-265

[21] Reva OM, Borsuk SP. Appliance of area under air traffic controller estimate function for main decision taking dominant determination. Aerospace Technic and Technology. 2016;**7**(134): 157-163

[22] Borsuk S. New methods for air traffic controller main solution taking dominant determination concerning their attitude to risk. Logistics and Transport. 2017;**1**(33):25-29

[23] Reva OM, Borsuk SP. Comparison of main decision making dominant of air traffic control students for different flights separation norms. In: Urban and Regional Transport Problems; 17-19 October 2015; Kharkov. 2015. p. 37

[24] Reva OM, Borsuk SP. Appliance of area under air traffic controller estimate function for main decision taking dominant determination. In: XXI International Propulsion Engineering Congress; 5-10 September 2016; Kharkov. 2016. p. 69

[25] Reva OM, Borsuk SP. Standard Plots of Main Decision Taking Dominant Determined with Double Lotteries Method. SLA-2016; 13-15 September 2016; Kherson. 2016. pp. 144-148

[26] Reva OM, Borsuk SP, Mirzoev BM, Moukhtarov PS. Comparative analysis of main solution taking dominants for students and professional air traffic controllers. In: XXIII International Propulsion Engineering Congress; 4-9 October 2018; Koblevo. 2018. p. 73

[27] Reva OM, Borsuk SP. Air traffic controllers attitude to the aircraft flight level norms violation. In: 2014 International Conference on Industrial Electronics and Engineering (ICIEE 2014); 1-2 May 2014; Hong Kong: WIT Transactions on Engineering Sciences, Vol. 93. 2015. pp. 575-582

[28] Reva OM, Borsuk SP. Measurement of air traffic control students proportion depending on their attitude to risk at 10-km flight norms violation. In: 2nd International Conference on Intelligent Materials and Measurement; 30-31 December 2015; Koh Samui, Thailand. 2015. p. 3

[29] Reva OM, Borsuk SP. Research of air traffic control students proportion concerning their attitude to risk. In: International Conference on Industrial Technology and Management Science (ITMS 2015); 27-28 March 2015; Tianjin, China: Atlantis Press, Computer Science Research. Vol. 34. pp. 1631-1634

[30] Reva OM, Borsuk SP, Mirzoev BM, Moukhtarov PS. Proactive determination of the influence of air traffic control experience on relation to the risk. Aerospace Technic and Technology. 2018;**5**(149):80-87

[31] Keeney RL, Raiffa H. Decisions with Multiple Objectives: Preferences and Value Tradeoffs [Translated]. Moscow: Radio I svyaz; 1981. p. 560

[32] Grant S, Van Zandt T. Expected Utility Theory, INSEAD Business School Research Paper No. 2007/71/EPS. 2007. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1033982 [Accessed: 25 June 2019]

[33] Rules of Medical Investigation of Air Accidents. Approved by Decree of

Ukrainian Derzhaviasluzhba. 2005. p. 919

[34] Kozeletsky Y. Psychological Decision Theory. Moskow; 1979. p. 504

[35] Fomenko YM. Risk triangle in system analysis of air traffic controllers professional activity. Problems of Informatization and Management. 2006;**3**:147-151

[36] Reva OM, Borsuk SP. Influence of Flight Norms Appliance Peculiarities Upon Particularity of Air Traffic Controllers Desirability Levels. Kherson: The Scientific Bulletin of Kherson State Maritime Academy; 2015. pp. 281-289

[37] Reva OM, Moukhtarov PS, Mirzoev BM, Nasirov SS. Indexes of Air Traffic Controllers Aspiration Levels at Flight Separation Norm Change. Vital Activity Support on Transport and Manufacture; 18-19 September 2014; Kherson. 2014. pp. 136-142

[38] Reva OM, Borsuk SP. Pilot analysis of air traffic controllers desirability levels on the specter of the horizontal air space flight separation norms. Aerospace Science and Technology. 2015;**9**(126):153-160

[39] Borsuk SP. Estimation of air traffic control student desirability level during violation of separation norm in 12 kilometers. Education. 2015;**3**(10): 168-171

[40] Reva OM, Borsuk SP. Air traffic control students tendencies of desirability levels during flight norms violations. 6th international conference on applied human factors and ergonomics, 26-30 July 2015; Las Vegas, Nevada, USA. Procedia Manufacturing. 2015;**3**:3049-3053

[41] Borsuk SP. Properties of composite linguistic variables modifiers. Electronics and Control Systems. 2012; **3**(33):152-157

[42] Reva OM, Borsuk SP. Fuzzy model of air traffic controllers attitude to the risk of potential conflicts situation appearance. Aerospace Science and Technology. 2013;**10**:214-221

[43] Reva OM, Borsuk SP, Shulgin VA. Finding of boarder risk levels during air space flight levels norms violation. Aerospace Science and Technology. 2014;**9**:151-156

[44] Reva AN, Borsuk SP. Fuzzy risk estimation of lack of compliance between ICAO SHELL model blocks "loveware"-"procedures". In: ISDMCI-2014 Zalizniy Port; 28-31 May 2014; Kherson. 2014. pp. 153-155

[45] Reva AN, Borsuk SP. Fuzzy model of air traffic controller attitude to the risk during decision making. In: 5th International Conference on Applied Human Factors and Ergonomics (AHFE – 2014); 19–23 July 2014; Kraków, Poland. 2014. pp. 6229-6238

[46] Reva O, Borsuk S. ATC risk level estimation of distance between aircraft during flight level rules violation. In: Aviation in the XXI-St Century: The Sixth World Congress. Safety in Aviation and Space Technologies; 23-25 September 2014; Kyiv, Ukraine. 2014. pp. 9.11-9.13

[47] Reva A, Mirzayev B, Mykhtarov P, Nasirov SH. Features of ICAO "risk triangle" solution of human factors complicated standards of the airspace separation. In: Aviation in the XXI-st Century: The Sixth World Congress. Safety in Aviation and Space Technologies; 23-25 September 2014; Kyiv, Ukraine. 2014. pp. 9.272-9.276

[48] Reva OM, Borsuk SP. Fuzzy model of air traffic controller attitude to the risk of potentially conflict situation

happening. In: XVIII International Propulsion Engineering Congress Rybachye; 14-19 September 2013; Kharkiv. 2013. p. 130

[49] Borsuk SP. Information supply for instructor decision support intellectual module according to human factor in air traffic control trainer. Electrotechnic and Computer Systems. 2015;**17**(93): 55-62

[50] Miller G et al. Psychological Review. 1956;**63**:81-97

[51] Reva OM, Kamyshin VV, Shulgin VA, Nedbay SV. Fuzzy Models of Ergonomical Qialimetry of Piloting Accuracy, Rivne. 2010. p. 106

[52] Kamishin VV, Reva OM. System Analysis Methods in Qualimetry of Education-Upbringing Process, Kyiv. 2012. p. 270

[53] Reva OM, Borsuk SP. ATC risk level estimation of distances between aircraft during flight level rules violations. In: Proceedings the Sixth World Congress “Aviation in the XXI-St Century” “Safety in Aviation and Space Technologies”; 23-25 September 2014; Kyiv. Vol. 3. 2014. pp. 9.11-9.13

[54] Reliability and Efficiency in Technique Handbook. Efficiency of Technical Systems; Moscow. 1988. p. 328

[55] Zadeh LA. The concept of a linguistic variable and its application to approximate reasoning. Information Sciences. 1975;**8**(3):199-249

[56] Reva AN, Shulgin VA, Borsuk SP, et al. Multiplicative approach to integral evaluation of aviation operators proficiency level. Elmi məcmuələr: Jurnal Milli Aviasiya Akademiyasinin. 2014;**16**(3):42-51

[57] Reva O, Borsuk S, Kharchenko V. Multiplication of air accidents frequency and Hazard desirability coefficients for ICAO safety risk tolerability matrix solution. Logistics and Transport. 2015. No 1. pp. 63-69

[58] Reva OM, Borsuk SP, Mirzoev BM. Integrative estimate of air traffic control students attitude to the danger of light level norms violation. Science-Based Technologies. 2016;**1**(29):96-101

[59] Reva OM, Borsuk SP, Moukhtarov PS, Mirzoev BM. Aggregated Estimate Method Development for Air Traffic Controllers Attitude to Risk MINNT-2015; 26–28 May 2015; Kherson. 2015. pp. 72-75