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MULTIPLICATIVE EVALUATION OF INFLUENCE OF THE ORGANIZATIONAL RISK FACTORS ON FLIGHT SAFETY IN AIR TRAFFIC CONTROL

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Abstract

Purpose: *to systematize the risk factors of organizational nature in Air Traffic Control system and to evaluate their complex influence on flight safety.* ***Methods:*** *the hazard degree of organizational factors in air traffic control has determined by the method of expert assessments, the scale of acceptability (admissibility) of the risk factors of organizational nature has constructed on the basis of the fuzzy sets theory with the use of linguistic variables. Results: it has revealed that air traffic control systems and equipment have the most significant influence on flight safety, company management and structure – the least one. The multiplicative function for evaluation of the flight safety in air traffic control has obtained, which allows checking the conformity of the values of organizational risk factors to the maximum permissible level of hazard.* ***Discussion:*** *proposed methodology for evaluation of the organizational risk factors influence on flight safety in air traffic control will allow developing the safety passports that can be applied by the State Aviation Administration of Ukraine during the certification inspections of air navigation service providers to compare the normative and actual indicators of their activities.*

Keywords: air traffic controller; coefficient of significance; expert questioning; flight safety; pairwise comparison method; ranking; risk factors; spider diagram.

1. Introduction

Flight safety is a condition, in which possibility of causing damage to people and property is reduced to an acceptable level and maintained at this or lower level through a continuous process of detecting hazardous factors and risk management [1].

Over the year 2017 the Aviation Safety Network [2] recorded a total of 10 fatal aircraft accidents, resulting in 44 occupant fatalities and 35 persons on the ground. This makes 2017 the safest year ever, both by the number of fatal accidents as well as in terms of fatalities. In 2016 Aviation Safety Network recorded 16 accidents and 303 lives lost. Five accidents involved cargo flights, five were passenger flights. Given the expected worldwide air traffic of about 36,8 millions flights, the accident rate is one fatal passenger flight accident per 7,36 millions flights. Since 1997 the average number of aircraft accidents has shown a steady and persistent decline due to the continuing flight safety-driven efforts by international aviation organisations. But the analysis of flight safety in Air Traffic Control (ATC) system [3] indicates the lack of attention of air navigation service providers to the organizational aspects, in particular, the division of responsibility, the coordination of operational question, the development and improvement of procedures, control over documentation in the implementation of quality management systems and flight safety. Issue of organization of activities remains the most critical element and requires careful attention.

Elimination of accidents remains the key point for all kinds of aviation activity. But it is impossible for aviation systems to be completely free of hazardous factors and associative risks. Neither human activity nor human designed systems is completely free of operational errors and its consequences [1, 4]. Flight safety is a dynamical parameter of aviation system. Thus risk factors should continuously mitigate. It is important to note that the adoption of indicators for the effectiveness of safety of flights is often influenced by internal and international standards, as well as cultural features [5]. When the risk factors and operational errors are reasonably monitored, flight safety can be managed [1]. Risk is an integral part of any aviation activity. A key function of safety management systems is risk management, which is carried out to ensure acceptable levels of safety. Risk management is performed in relation to the identified hazards and includes: identifying factors that threaten the safety of flights; analysis of the revealed factors; evaluating the magnitude and acceptability of the risks associated with these factors; development of means for reducing risks to admissible levels; control of residual risks during operation [6 – 7].

The global air traffic management (ATM) operational concept presents the ICAO vision of an integrated, harmonized and globally interoperable ATM system. The planning horizon is up to and beyond 2025 [8]. The integration of the concept components may be balanced to achieve different expectation outcomes. All concept components must be present in each State's or region's ATM system to some degree. That is not to say that any particular component will be used as a major contributor to an outcome in a particular State or region, or that a great deal of automation or technology will be required to deliver against that component; however, they must be considered at each evolutionary stage. Safety can never fall below minimum accepted levels. In fact, it should be argued that any change to the ATM system for an outcome not directly aimed at enhancing safety should, nonetheless, strive to achieve its net increase (Fig. 1). The safety balance model indicates that, on the whole, the system needs to retain a safety tension to achieve an acceptable level of safety. The ATM system is based on the provision of services. This framework considers all resources: airspace, aerodromes, aircraft and humans, to be part of the ATM system. The description of the concept components is based on realistic expectations of human capabilities and the ATM infrastructure at any particular time in the evolution to the ATM system described by this operational concept and is independent of reference to any specific technology.

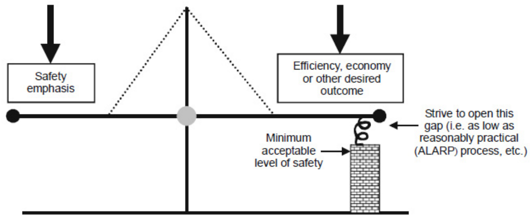

Fig. 1. Safety balance model (Source: Global Air Traffic Management Operational Concept: ICAO [8])

Efficiency addresses the operational and economic cost-effectiveness of gate-to-gate flight operations from a single-flight perspective. The effectiveness is the measure for decision-making how the system provides the desired output or not. Being effective means producing the right output in terms of quantity and quality. When the system is ineffective, the system is out of control and it needs a major correction.

The authors suggest to systematize the risk factors of organizational nature in ATC system and to evaluate their complex influence on flight safety [9 – 10].

2. Analysis of latest research and publications

Starting from the period of the "organizational era" (1990s – present time), flight safety has become systematically considered, covering organizational, human and technical risk factors.

Also, the concept of "organizational accident" appeared at this that time in aviation due to the influence of organizational culture and policy on the effectiveness of the control system in terms of risk factors identification. In addition, routine data collection and analysis which was limited to the use of data obtained during the investigation of aviation events and serious incidents, was significantly improved with new proactive approach to the problems of flight safety. The new approach is based on the use of proactive and reactive methods in the process of collecting and analyzing data in order to monitor known risk factors and identify new emerging problems in the field of flight safety. New opportunities have served as a justification for the further movement towards the creation of an effective mechanism for managing safety of flights [1, 11]. The concept of "organizational accident" which underlies the model of "Swiss-Cheese" by Professor James Reason [1, 5, 11 – 12], includes a number of structural elements, such as: conditions at the workplace, latent conditions, active failures, defences and others (Fig. 2).

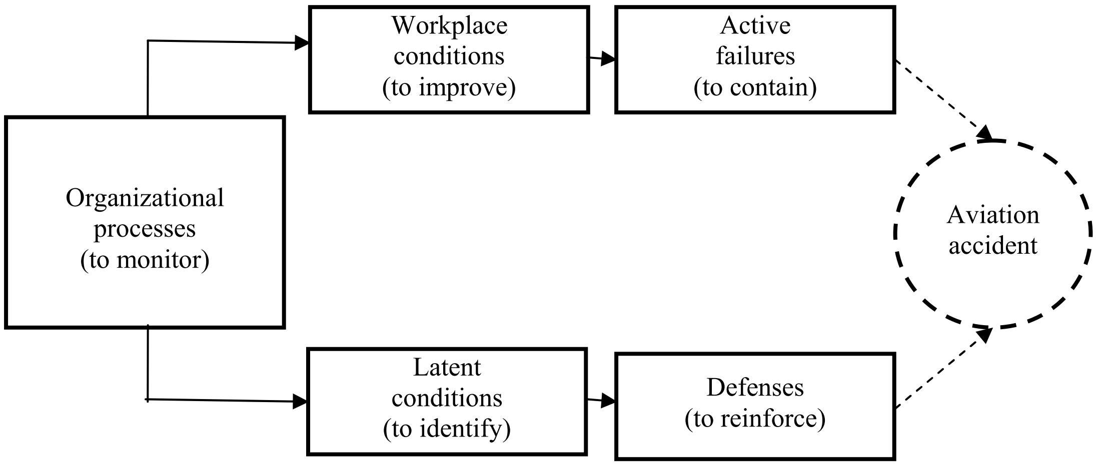

Fig. 2. Structural scheme of "Swiss-Cheese" model by Professor James Reason

The first structural element is the organizational processes – the types of activities that are directly controlled by aviation system within reasonable limits. The two main organizational processes in the field of flight safety are resource allocation and information sharing. Failures or shortcomings of these organizational processes lead to disruptions in two directions. The first one is the way of latent conditions. In general, latent conditions can be divided into two large groups. The first group – insufficient detection of hazardous factors and management of risk factors for flight safety; the second group is a forced violation of the rules and procedures by the operating personnel as a result of the extreme lack of resources. There are lots of potential malfunctions for aviation system protections under latent conditions. Those system protections are usually the last line of defence to control latent conditions, as well as to prevent the consequences of human error. Most of the risk reduction methodologies for flight safety are based on the enhancement of existing protection tools or development of new tools.

Another area of organizational processes is the conditions at the workplace that directly affect the performance of people in aviation sphere. The non-optimal conditions in the workplace lead to active failures by the operational staff (errors or violations). From the "organizational accident" point of view, flight safety measures should be directed at monitoring organizational processes in order to detect latent conditions and thus enhance protection facilities. Flight safety measures must also be aimed at improving workplace conditions to reduce number of active failures, as the mutual connection of all these factors leads to flight safety failures.

There are number of risk factors of organizational nature which are mentioned in ICAO documents [1, 5, 11 – 12]. In order to manage risk factors, a procedure for identifying hazardous organizational factors and quantifying their impact on flight safety is necessary and relevant.

3. Research tasks

1. Identification of the organizational factors that affect flight safety in ATC.
2. Determination of the degree of influence of organizational risk factors on flight safety in ATC.
3. Obtaining a multiplicative function for evaluation of the flight safety in ATC.

4. The solution of the problem

In order to determine the degree of influence of organizational risk factors on flight safety in ATC, an expert questioning has conducted on 30 area air traffic controllers at Lviv Regional Branch of UkSATSE [9 – 10]. The questionnaire has formed in accordance with the “Swiss-Cheese” model by Professor James Reason on the based of the structural elements of the “organizational accidents”. It has consisted of eight selected main groups of organizational factors: operational environment, procedures and manuals, engineering procedures and maintenance, cooperation between ATC sectors, ATC systems and equipment, infrastructure, airspace structure, company management and structure (Table 1).

Table 1

Groups of organizational factors that influence on flight safety in air traffic control

Group number	Group name	Group description
1	Operational environment	Factors, connected with physical environment (temperature, air circulation, illumination, level and timing of noise, atmospheric pressure etc).
2	Procedures and manuals	Factors, associated with adequacy/inadequacy of procedures/manuals, failure to comply or possibility/impossibility of compliance with them.
3	Engineering procedures and maintenance	Factors, connected with work of engineers, including routing technical checks and equipment maintenance after the failure. In addition, procedures of design, installation and implementation of new equipment.
4	Cooperation between ATC sectors	Factors, relating to the technical aspects of system operations between air traffic control sectors as well as between adjacent air traffic control systems (compatibility of coordination procedures, Letters of Agreement, acceptance of information from other sources).
5	ATC systems and equipment	Factors, associated with work of the hardware, software and its compatibility.
6	Infrastructure	Factors, connected with aerodrome (physical parameters, configuration of manoeuvring areas, restriction zones) and environmental layout.
7	Airspace structure	Factors, relating to classification of airspace structure, route network, capacity, configuration of sectors.
8	Company management and structure	Factors, connected with the style of company management at all levels, company ethics.

Each expert has filed the matrix of individual preferences. With the help of the pairwise comparison method and ranking [13], the significance rank of each group of factors according to individual expert`s priorities has determined. Next step was to form the group preferences matrix and to obtain the average index of the group of experts concerning each group of organizational factors R_{gri} and rank of each group R'_{gri}. The competences of experts have considered being equal. Two stages of questioning have performed in order to achieve the agreement among professionals on level of influence on safety by each group [14]. Level of significance of each group of organizational risk factors has described with weight coefficients ω_i. The weight coefficient has determined by the formula (1):

$$\omega_i = \frac{C_i}{\sum_{i=1}^{n} C_i}, \qquad (1)$$

where $C_i = 1 - \frac{R'_{gri} - 1}{n}$ – is the intermediate assessment;

R'_{gri} – is the rank of i-group of organizational risk factors.

The obtained weight coefficients of groups of organizational risk factors that affect the safety of flights in ATC are presented in Table. 2.

Table 2

Calculation of weight coefficients of organizational risk factors' groups

Group number	Group rank, R'_{gri}	Intermediate assessment, C_i	Weight coefficient, ω_i
1	7	0,250	0,06
2	3	0,750	0,17
3	6	0,375	0,08
4	2	0,875	0,19
5	1	1,000	0,22
6	5	0,500	0,11
7	4	0,625	0,14
8	8	0,125	0,03
$\sum$		4,5	1

The graphic interpretation of the results of an expert questioning in the form of a histogram is shown in Fig. 3.

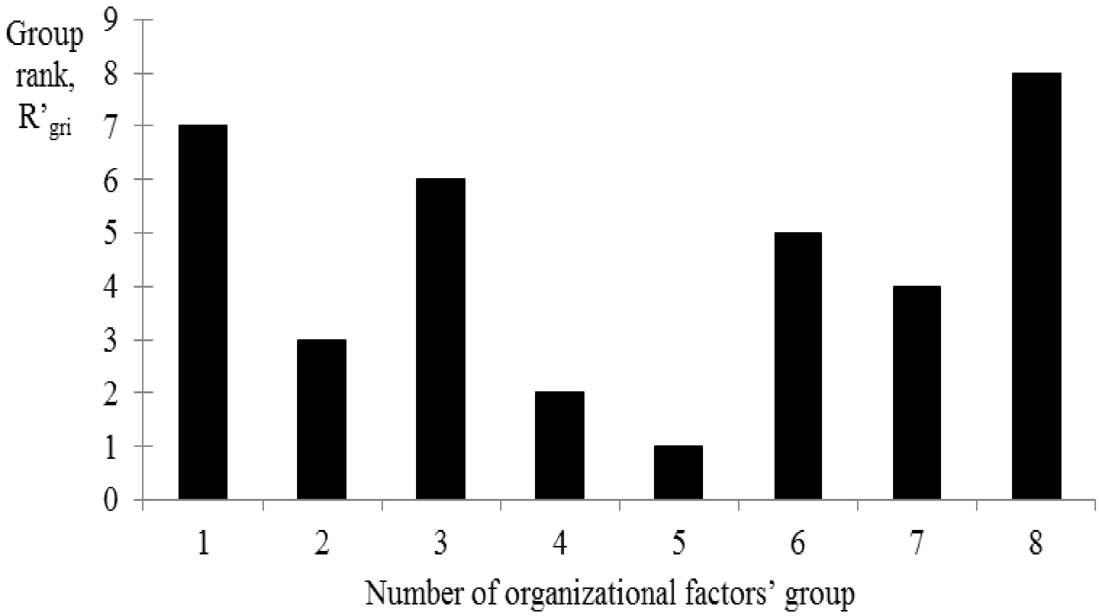

Fig. 3. Graphic interpretation of expert answers

As a result of performed expert questioning, the following order of groups of organizational risk factors depending on the degree of their influence on flight safety has achieved (from the most significant to the least significant one):

1. ATC systems and equipment (R_{gr5}=2,63; R'_{gr5}=1; ω_5=0,22).
2. Cooperation between ATC sectors (R_{gr4}=3,12; R'_{gr4}=2; ω_4=0,19).
3. Procedures and manuals (R_{gr2}=3,5; R'_{gr2}=3; ω_2=0,17).
4. Airspace structure (R_{gr7}=3,98; R'_{gr7}=4; ω_7=0,14).
5. Infrastructure (R_{gr6}=4,38; R'_{gr6}=5; ω_6=0,11).
6. Engineering procedures and maintenance (R_{gr3}=5,27; R'_{gr3}=6; ω_3=0,08).
7. Operational environment (R_{gr1}=6,37; R'_{gr1}=7; ω_1=0,06).
8. Company management and structure (R_{gr8}=6,75; R'_{gr8}=8; ω_8= 0,03).

The results of the expert questioning have presented as a system of advantages (2):

$$\begin{aligned} &R'_{gr5} \succ R'_{gr4} \succ R'_{gr2} \succ R'_{gr7} \succ \\ &\succ R'_{gr6} \succ R'_{gr3} \succ R'_{gr1} \succ R'_{gr8}, \end{aligned} \quad (2)$$

where R'_{gri} – is the rank of i-group of organizational risk factors.

It is clear that out of all groups of organizational risk factors "Air traffic control systems and equipment" group has the most significant impact on flight safety in ATC, and "Company management and structure" – the least one.

5. Results and discussions

In accordance with the matrix of the risk index [1], which takes into account the seriousness and probability of possible consequences, the scale of acceptability (admissibility) of organizational risk factors has constructed on the basis of the fuzzy sets theory with the use of linguistic variables [15]: extreme risk (100 points), high risk (80 points) moderate risk (60 points), low risk (40 points) and scarce risk (20 points). To ensure a sufficient level of flight safety, the risk indicators must be no more than 60 points taken at the maximum permissible level of hazard. The actual significance of the level of hazard to the groups of organizational factors has determined by questioning the air traffic controllers at Lviv Regional Branch of UkSATSE and statistical processing of the results, which confirmed the consistency of expert opinions.

The results of flight safety evaluation at Lviv Regional Branch of UkSATSE on the basis of analysis of organizational risk factors are presented in Table 3.

Table 3

Results of the flight safety evaluation in ATC at Lviv Regional Branch of UkSATSE

Group of organizational factors	Operational environment	Procedures and manuals	Engineering procedures and maintenance	Cooperation between ATC sectors	ATC systems and equipment	Infrastructure	Airspace structure	Company management and structure
Weight coefficient (degree of influence)	0,06	0,17	0,08	0,19	0,22	0,11	0,14	0,03
Maximum allowable level of hazard	60	60	60	60	60	60	60	60
Actual level of hazard	20	35	25	35	20	25	30	35
Parameter of maximum allowable hazardous level	1,28	2,01	1,39	2,18	2,46	1,57	1,77	1,13
Parameter of expertise of actual hazardous level	1,20	1,83	1,29	1,97	1,93	1,42	1,61	1,11
The difference between maximum allowable and actual parameters of hazardous level	0,08	0,18	0,10	0,21	0,53	0,15	0,16	0,02

Convolution of multiparametric indicator of the flight safety status in ATC on the basis of analysis of the organizational risk factors to the scalar indicator has carried out in a multiplicative way (3):

$$W = \prod_{i=1}^{n} f_i^{w_i} = g(f_i(w_i)), \qquad (3)$$

where f_i – is the level of hazard of i-group of organizational factors;

ω_i – is the weight coefficient which taking into account the probability and severity of influence of i-group of organizational factors.

The results of the expert questioning are presented graphically using spider diagram (Fig. 4).

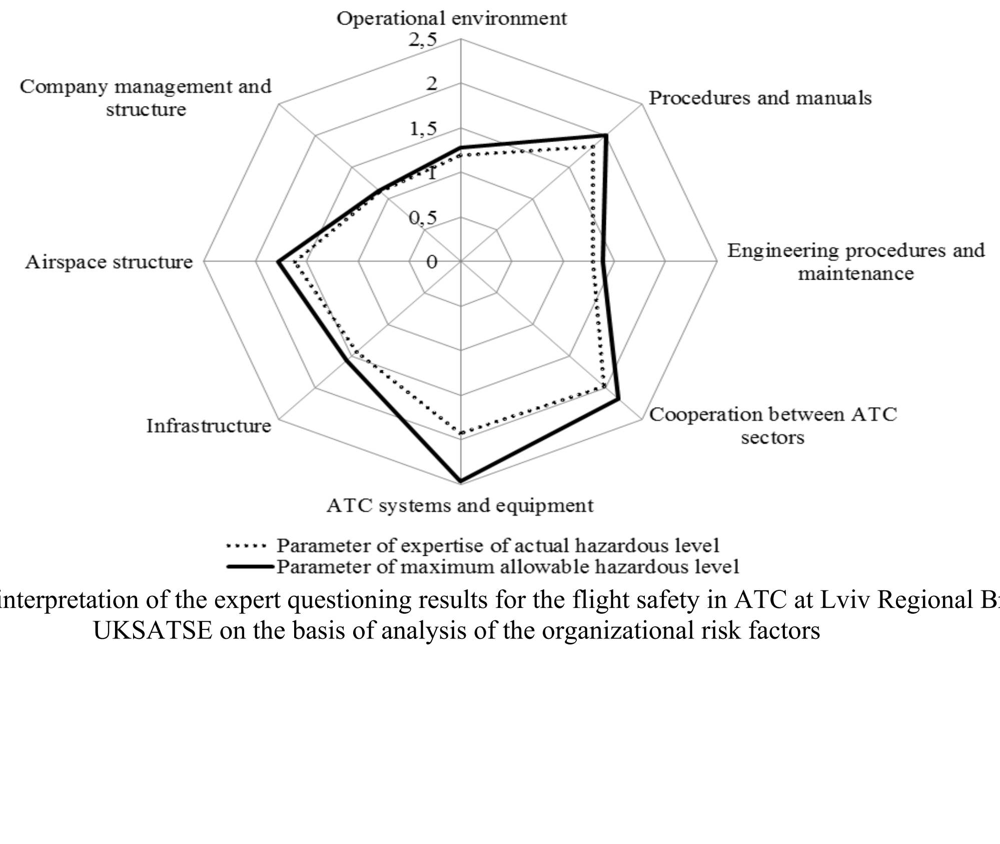

Fig. 4. Graphic interpretation of the expert questioning results for the flight safety in ATC at Lviv Regional Branch of UKSATSE on the basis of analysis of the organizational risk factors

With the help of data from Table 2 the authors have received maximum allowable W_{al} and actual W_{act} value of multiplicative function for evaluation of flight safety level in ATC at Lviv Regional Branch of UkSATSE on the basis of organizational factors:

$$W_{all} = 60^{0,06} \cdot 60^{0,17} \cdot 60^{0,08} \cdot 60^{0,19} \times$$
$$\times 60^{0,22} \cdot 60^{0,11} \cdot 60^{0,14} \cdot 60^{0,03} = 60{,}99;$$
$$W_{act} = 20^{0,06} \cdot 35^{0,17} \cdot 25^{0,08} \cdot 35^{0,19} \times$$
$$\times 20^{0,22} \cdot 25^{0,11} \cdot 30^{0,14} \cdot 35^{0,03} = 27{,}33.$$

Comparison of flight safety results at Lviv Regional Branch of UkSATSE were performed on the basis of maximum allowable level of hazard and expertise of actual hazardous level of organizational factors' groups $\Delta W = W_{all} - W_{act}$ = 60,99 – 27,33 =33,66.

An example of the expertise results, presented in Fig. 4, shows the correspondence of the values of all groups of organizational risk factors to the maximum permissible level of hazard, which indicates a high flight safety index in air traffic control at this Regional Branch.

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6. Conclusions

The core of the flight safety management practical mechanism in ATC system is the purposeful search for risk factors that lead to aviation accidents in order to protect from their influence. Identification of risk factors is implemented in the form of regular monitoring, collection, processing and accumulation of information about factors that have caused aviation accidents.

The model of "Swiss-Cheese" by Professor James Reason shows that the organizational risk factors play a significant role in the causality of aviation accidents and require a comprehensive research.

Organizational factors that influence on the flight safety in ATC have systematized in eight groups: operational environment, procedures and manuals, engineering procedures and maintenance, cooperation between air traffic control sectors, ATC systems and equipment, infrastructure, airspace structure, company management and structure.

It has revealed that the most significant influence on flight safety has "ATC systems and equipment" group of organizational risk factors and the least – "company management and structure".

The multiplicative function for evaluation of the flight safety in ATC has obtained, which allows checking the conformity of the values of organizational risk factors to the maximum permissible level of hazard.

Proposed methodology for evaluation of the organizational risk factors influence on flight safety in ATC will allow developing the safety passports that can be applied by the State Aviation Administration of Ukraine during the certification inspections of air navigation service providers to compare the normative and actual indicators of their activities.

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Мультиплікативна оцінка впливу організаційних факторів ризику на безпеку польотів при управлінні повітряним рухом

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Мета: систематизувати фактори ризику організаційного характеру в системі управління повітряним рухом та оцінити їх комплексний вплив на безпеку польотів. **Методи дослідження:** ступінь небезпеки організаційних факторів при управлінні повітряним рухом визначено методом експертних оцінок, шкалу прийнятності (допустимості) факторів ризику організаційного характеру побудовано на основі теорії нечітких множин із застосуванням лінгвістичних змінних. **Результат:** виявлено, що технічні системи та засоби управління повітряним рухом здійснюють найсильніший вплив на безпеку польотів при управлінні повітряним рухом, а політика управління та структура компанії – найслабший. Отримано мультиплікативну функцію оцінювання стану безпеки польотів при управлінні повітряним рухом, яка дозволяє перевірити відповідність значень організаційних факторів ризику встановленому максимально допустимому рівню небезпеки. **Обговорення:** запропонована методика оцінювання впливу організаційних факторів ризику на безпеку польотів при управління повітряним рухом дозволить розробити паспорти безпеки, які можуть застосовуватись Державіаслужбою України при проведенні сертифікаційних перевірок провайдерів аеронавігаційних послуг для порівняння нормативних та фактичних показників їх діяльності.

Ключові слова: авіадиспетчер; безпека польотів; діаграма «павук»; експертне опитування; коефіцієнт значущості; метод парних порівнянь; ранжування; фактори ризику

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Мультипликативная оценка влияния организационных факторов риска на безопасность полетов при управлении вождушным движением

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Цель: систематизировать факторы риска организационного характера в системе управления воздушным движением и оценить их комплексное влияние на безопасность полетов. **Методы исследования:** степень опасности организационных факторов при управлении воздушным движением определена методом экспертных оценок, шкала приемлемости (допустимости) факторов риска организационного характера построена на основе теории нечетких множеств с применением лингвистических переменных. **Результат:** выявлено, что технические системы и средства управления воздушным движением оказывают наиболее сильное влияние на безопасность полетов при управлении воздушным движением, а политика управления и структура компании – наиболее слабое. Получена мультипликативная функция оценивания состояния безопасности полетов при управлении воздушным движением, которая позволяет проверить соответствие значений организационных факторов риска установленному максимально допустимому уровню опасности. **Обсуждение:** предложенная методика оценивания влияния организационных факторов риска на безопасность полетов при управлении воздушным движением позволит разработать паспорта безопасности, которые могут применяться Госавиаслужбой Украины при проведении сертификационных проверок провайдеров аэронавигационных услуг для сравнения нормативных и фактических показателей их деятельности.

Ключевые слова: авиадиспетчер; безопасность полетов; диаграмма «паук»; коэффициент значимости; метод парных сравнений; ранжирование; факторы риска; экспертный опрос

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