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APPLICATION OF THE FUZZY SETS THEORY FOR ENSURING FLIGHT SAFETY OF THE CIVIL AVIATION SERVICE PROVIDERS IN THE CONDITIONS OF THE UNCERTAINTY STATUSES OF THE AVIATION SYSTEM

(Presented by the Interstate Aviation Committee)

EXECUTIVE SUMMARY

This paper contains brief information on the application of the Fuzzy Sets Theory methods in the identification of the critical combinations of the aviation systems' elements of the safety management system (SMS) type for the purpose of ensuring flight safety and operational activity of the organizations that are civil aviation service providers (aviation enterprises engaged in commercial air transportation, aerial works, legal entities engaged in civil aircraft maintenance, air navigation services for aircraft flights, educational organizations and aviation centres engaged in training civil aircraft pilots, air traffic controllers and administrators of certified civil aviation aerodromes).

Strategic Objectives:	This paper is related to the Strategic Objective "Flight Safety"
Financial implications:	Without any financial implications
References:	Annex 19 – *Safety Management* Doc 9859, *Safety Management Manual (SMM)* Kuklev E. et al. Flight Safety and Aviation Risk. Singapore: Springer, 2019.

[1] English and Russian versions provided by IAC.

1. INTRODUCTION

1.1 The basis for the practical application of the Fuzzy Sets Theory for ensuring flight safety is the study of the properties of the uncertainty range of the civil aviation service providers' statuses. The research is conducted in accordance with the International Civil Aviation Organization (ICAO) Integrated Risk Management (IRM) concept. This concept, stated in p.1.4.3 of ICAO Doc 9859, *Safety Management Manual* (4th edition, 2018), suggests to evaluate the needs in the interdependence of functional systems (search for "feedbacks"). IRM is aimed to reduce the overall risk in the system, including functional systems of the civil aviation service provider. This standard provision regulates standard activity audit procedures based on the normative monitoring results' analysis. Here we propose a new approach to solving the ICAO task of "finding feedbacks" between the system parameters using the Fuzzy Sets Theory for the two sets of the service providers' performance indicators: audit indicators related to quality and indicators characterizing flight safety and operational procedures in the integrated quality and safety management system of the civil aviation service provider.

2. DISCUSSION

2.1 Presently, the analysis of the effectiveness of ensuring aircraft flight safety uses the results of the standard monitoring by measuring flight safety indicators. In order to assess flight safety level methods are used based on the calculation of the sum of the points characterizing risk value on the basis of the average set of indicators with the degree of the confirmation of the final risk value by the "success probability" type value. These methods do not clearly and distinctly reflect the uncertain state of the estimates made. Therefore, there is a need to improve the known solutions on the basis of the audit, which is taking into account the possible parameter interconnections (meaning the ICAO task of the "feedbacks" identification), but there are no recommendations on the possible methods of finding such solutions presently provided by ICAO.

2.2 At the same time, p.4.3.2.2 of ICAO Doc 9859 suggests to identify correlations between the two types of indicators, which in turn may improve the effectiveness of ensuring flight safety. The new flight safety management concept is based on determining of the interdependencies of the elements in the system. At the same time, ICAO Doc 9859 does not provide any specific methods for monitoring and measuring flight safety indicators, taking into account the interconnectedness of the fundamental modules in the aviation system.

2.3 P. 4.3.2.2 of ICAO Doc 9859 gives the interconnection between the indicator of the ornithological flight support procedures execution and the indicator related to the bird strike in flight. It also gives an example of the influence of the pilot training level on the flight safety indicator related to the number of overruns. This example is an essential designator, but only a particular one, since it cannot be used in case of the uncertainty of such type as the negative impact of the human factor on flight safety.

2.4 The task of determining the interconnection between two types of quality and flight safety indicators may be successfully solved in the integrated quality and flight safety management system of the civil aviation service provider using the Fuzzy Sets Theory in the conditions of uncertainty in the statuses of the system as a whole and its individual elements, including factors of various safety "threats".

2.5 In the civil aviation of the Russian Federation, a number of civil aviation service providers (aviation enterprise, aerodrome operator) have developed and successfully applied methods for the event chains' criticality analysis, taking into account fuzzy measurability of the chain elements status

uncertainty according to the Fuzzy Sets concept based on the “fatal crash equation” construction methods, taking into account the results of the quality and flight safety indicators evaluation in the integrated quality and flight safety management system.

2.6 The uncertainty factor lies in the fact that in situations with rare events (according to ICAO) it is impossible to reliably predict the occurrence of physical failures, accidents in systems, aircraft fatal crashes or acts of unlawful interference. In fact, a "highly secure system" may not be very reliable, and vice versa. It is proposed to adopt a new scheme for determining risk under conditions of uncertainty based on a risk-based approach (according to ICAO). In accordance with this new provision, the problem of overcoming difficulties with the analysis of *states of uncertainty* is solved according to the scheme of using the scale of matrices for the "risks" analysis and compiling chains of events (scenarios) with a fuzzy measure of the occurrence of a risky event with great damage (fuzzy measurable uncertainty).

2.7 The method for measuring the fuzzy uncertainty is based on the procedures for processing arrays of results of the two most important modules of the quality management system and the flight safety management system, obtained under the typical monitoring of the service provider activities in the integrated quality and safety management system.

2.8 Within the framework of the quality management system and the flight safety management system integration, it is proposed to divide the indicators at the aviation enterprise into quality indicators and flight safety indicators according to the following principle: quality indicators establish the degree of procedures performance, flight safety indicators are determined in the form of deviations (errors, violations) from the established procedures. In this case, there is an "area of uncertainty", expressed in the degree of relationship between the two types of indicators, i.e. in proving the existence of "inverse relationship" between the indicators.

2.9 The correlations between quality indicators and flight safety indicators of a civil aviation service provider allow to detect and evaluate the degree of the aviation system elements criticality under the conditions of uncertainty. Critical are such elements of the aviation system, the chains of which can lead to an unfavorable event such as fatal crashes, accidents, serious aviation incidents, emergencies.

2.10 To find a fuzzy multi-criteria performance indicator, it is proposed to evaluate the inverse relationship between the factors affecting flight safety by conducting a typical correlation analysis of the indicator sets, obtained during repeated monitoring of the civil aviation service provider activity for a certain period.

2.11 A sequential chain of critical values of a fuzzy multi-criteria performance indicator allows you to find the level of acceptable risk in the aviation system, as well as to develop and apply corrective actions to eliminate the conditions for the occurrence of an adverse event with a high risk in the aviation system of the civil aviation service provider.

2.12 With the help of a fuzzy multi-criteria performance indicator, it is proposed to form a mathematical object in the form of an "integral risk", which sets the level of danger based on a preventive *(proactive)* forecast of the future damage possibility. To do this, based on the concept of Fuzzy Sets, a measure of the possibility of an event occurring (according to Zade) and a measure of harm are established - a consequence of an event possibility.

2.13 The mathematical mechanism (method) for the search for critical elements in the conditions of fuzzy measurable uncertainty of the integrated quality and safety management system of the civil aviation service provider includes the following steps:

a) quality indicators and safety indicators regulation into a single line of the matrix for continuous monitoring;

b) the division (splitting) of the civil aviation service provider indicators into two different sets - quality indicators and separately- flight safety indicators;

c) clustering of the civil aviation service provider integrated system is carried out according to the functional characteristics (for example, by classes: organization of flight work, continuing airworthiness, ground handling of aircraft, etc.);

d) establishing a procedure for continuous monitoring of the civil aviation service provider processes;

e) normalization of quality indicators and flight safety indicators in the topological space of the given hazard factors;

f) determination of correlations between the values of paired hazard indicators in the form of a fuzzy multi-criteria indicator of efficiency;

g) determination of the degree of consequences of the identified critical element of the aviation system using a risk assessment matrix;

h) checking the results of calculations using "adaptive sliding" and (or) "comparison" according to the "correlation of rows of the same dimension" principle;

i) drawing up a “fatal crash equation” (in the broad sense: an adverse event: an accident, an aviation incident) using a formula like “conjunctions of many logical factors that indicate the existence of dangerous physical hazards that affect the system and include the human factor negative manifestations”;

j) taking the corrective actions based on a risk-oriented approach; and

k) verification of the corrective actions effectiveness by re-audit and calculation of the multi-criteria indicators of the civil aviation service provider system elements effectiveness.

2.14 The implementation of the method from 2.13 in the field of civil aviation service providers’ activity (an aviation enterprise and an aerodrome operator) has confirmed the reliability of the results obtained and the pragmatism of a new approach to finding critical elements in the circumstances of uncertainty in the states of an integrated quality and safety management system.

3. CONCLUSION

3.1 A new form of audit and monitoring of the civil aviation service provider activities ensures an additional assessment of the identified inconsistencies in the systems to determine their

criticality. This form fully complies with the concept of a risk-based approach (according to ISO 9000 series) and contributes to improving the efficiency of the SMS of a civil aviation service provider.

3.2 The participants of the 41st Session of the ICAO Assembly are invited to take into consideration the information provided in this paper.

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