ТРАНСПОРТ

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FUZZY RISK ASSESSMENT OF AVIATION EVENTS

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ABSTRACT

The article presents the technique of fuzzy expert assessment of risk that existed at the time an event occurred. The risk assessment is based on matrix proposed by the Airline Risk Management Solution (ARMS) Group. The matrix allows assessing such risks in the numerical values of the conditional average. The values of the indicators in the cells of the matrix obtained by use of data processing got from aviation insurance.

In practice the risk assessment that existed at the time of the event is largely based on expert opinions, however ARMS Group does not offer the method of forming estimates expert group total opinion. Conventional methods of expert estimation and averaging of final grades is difficult due to the exponential nature of changes in risk values recorded in the cells, when considered by columns and by rows of the matrix.

The proposed method of risk assessment uses the approach adopted in the formation of membership functions according to expert estimates in the theory of fuzzy sets. Experts are invited to classify each event according to one of the categories of potential damage and the effectiveness of barriers parry (defenses) using all available information. Processing of results is conducted using the method of expert analysis of fuzzy data based on the approach of fuzzy set theory. The seriousness (damage) of the occurrence and effectiveness of the barriers considered as linguistic variables, each of which has four term sets. This approach allows taking into account the opinions of experts and obtaining valid estimates of risk do not necessarily coincided with fixed values of matrix cells.

Key words: risk, safety, expert assessment, grade of membership.

INTRODUCTION

Basic methodological problems in the development and implementation of safety management system (SMS) of aviation service providers that is mandatory in accordance with [1] are related with risk management. ICAO [2] recommends for evaluation and ranking of risk a matrix well known as "matrix of consequences and probability" [3].

The approach to risk assessment based on ICAO matrix has a number of disadvantages, analyzed in detail in [4]. We emphasize here that the implementation of any quantitative risk assessments that took place at the time of the event in vast majority of cases is very difficult because it is difficult to overcome the problem of assigning events to categories "the same". If nevertheless in some cases (when using converted "quantitative" matrix) one will be able to get any reasonable values of risk, it is fundamentally impossible to use them to obtain values for the integral of risk or to carry out "risk monitoring" (see [4]).

However, the misconception about the ability to "skip" any occurrence through the ICAO matrix and summarize risks proved to be resistant. Such attempts exist in the practice of the airlines at present time.

Awareness of these challenges prompted the Airline Risk Management Solution Group (ARMS) to take out the problem of risk assessment at the time of the event from the general scheme of risk management. The Group introduced the concept of assessing Event Based Risk (EBR) and the original matrix for indicator of risk classification – Event Risk Classification (ERC) [5, 6].

A significant part of assessments on this matrix got from expert surveys however, ARMS does not offer the method of calculating the coefficients of the ERC according to the expert survey. It seems appropriate to develop a method of expert data processing using the theory of fuzzy sets approach, given in [7].

EVENT RISK ASSESSMENT FOR THE TIME WHEN THE EVENT OCCURRED

The development of the aviation event can be represented by the diagram prepared based on ARMS approach (Fig. 1).

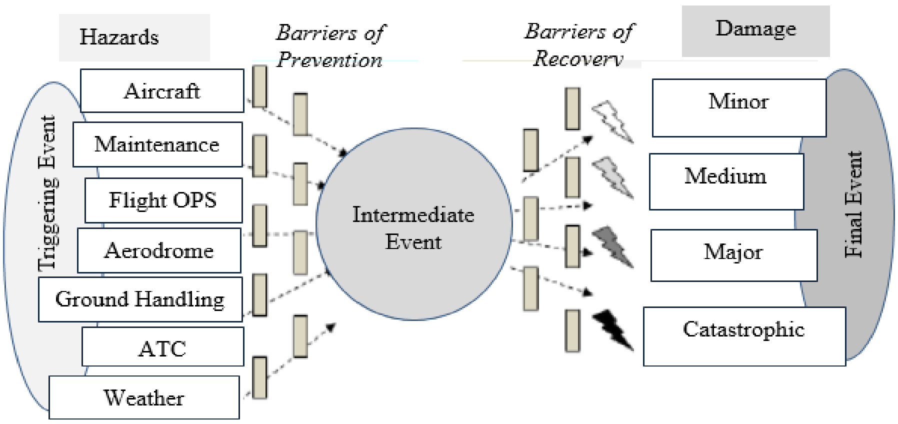

Fig. 1. Scheme of development of the aviation event with damage

The starting point is a triggering event coursed by a hazard. Many manifestations of hazards blocked by barriers of prevention. The barriers include right decisions and actions of the crew, cross-checking procedures, good ergonomics of the cockpit, as well as the actions of the air traffic controller, ground staff, etc. However these barriers may not work and then comes the "Intermediate event" (IE).

Another type of barriers - barriers of recovery hinder the transition of IE to the final event with damage. This type of barriers include correct crew responses to failures, correcting mistakes – their own and others and redundancy of aircraft systems. Safety barriers as natural elements of the scheme of development of the aviation events are analyzed in [8, 10].

The analyzed event is the IE, when barriers of prevention have been already broken. The IE had a specific outcome, but a possible outcome of an event could be much heavier. For example, such IE as loss of pilot-controller radio communication or takeoff without authorization could result in a collision. Thus. The damage is a random value it could take other values depending on the effectiveness of our barriers of recovery and accidental factors.

Assessment of risk, which took place at the time of the event – Event Based Risk (EBR), based on the fact that when analyzing the events we are concerned about two main issues:

1) What is the possible negative outcome of IE in the sense of possible damage?

2) To what extent is that the IE did not develop in event with damage: due to the barriers of recovery or due to a coincidence (in other words, how we were lucky)?

The answers to these questions evaluate the event in units of the ERC in the matrix of Fig. 2.

Question 1	Question 2			
To what damage could lead the most probable negative development of events?	What is the effectiveness of the remaining barriers between the intermediate event and the likely negative scenario for the development of a dangerous situation?			
	Very low	Low	Medium	High
Catastrophic	2500	500	100	50
Major	500	100	20	10
Medium	100	20	4	2
Minor	1			

Fig. 2. Matrix of assessment of Event Risk Classification (ERC)

The numerical values of ERC as explained in [5] correspond to the estimates obtained from the database of the aviation insurance. Graphical interpretation (Fig. 3) shows the exponential dependence.

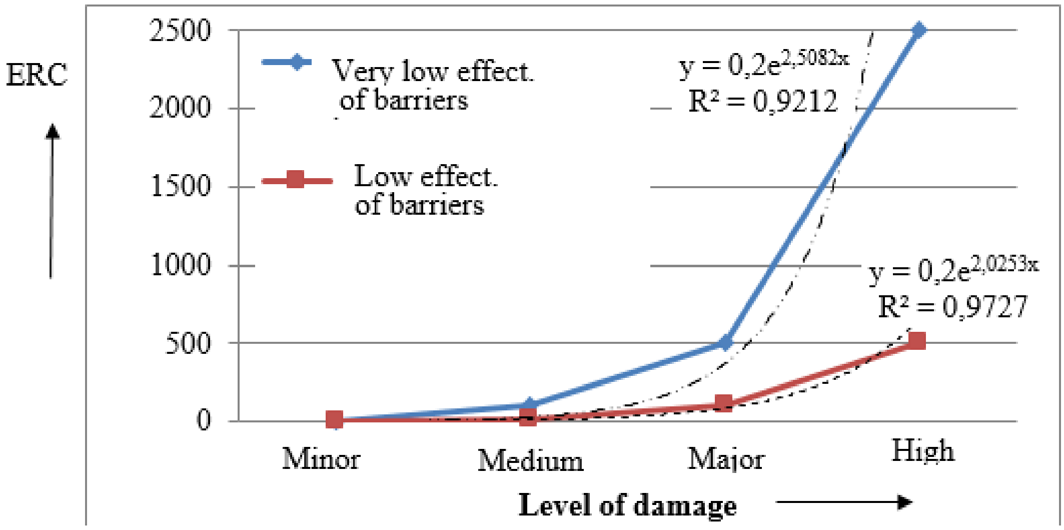

Fig. 3. The dependence of ERC from the damage for two variants of the efficiency of the barriers

With the received ERC indexes it is permissible to perform arithmetic calculations for any of the time intervals. You can also use these indexes as indicators in monitoring the level of safety.

EXPERT ESTIMATION AND DATA PROCESSING

The ERC indicator calculated using expert estimates. Experts are invited to evaluate events by answering the above two questions using the information available.

Each event has to be attributed to one of the categories of potential damage and the effectiveness of barriers of recovery. Expert marks his choice by digit 1, other values are marked with 0.The results of the evaluations are put in the tables the fragments of which shown in Fig. 4.

Expert	Level of Damage	Event 1	2	3	4	5	6	7
E1	Catastrophic	0	0	0	0	0	0	0
	Major	0	0	0	0	0	0	0
	Medium	0	1	1	0	0	0	1
	Minor	1	0	0	1	1	1	0
E2	Catastrophic	0	0	0	0	0	0	0
	Major	0	1	0	0	0	0	0
	Medium	0	0	1	1	1	1	0
	Minor	1	0	0	0	0	0	1
E3	Catastrophic	0	0	0	0	0	0	0

Expert	Effect. of Barriers	Event 1	2	3	4	5	6	7
E1	Very Low	0	1	1	0	0	0	0
	Low	0	0	0	1	0	1	1
	Medium	0	0	0	0	0	0	0
	High	1	0	0	0	1	0	0
E2	Very Low	0	1	0	0	0	0	0
	Low	0	0	0	0	0	0	0
	Medium	0	0	1	0	0	0	0
	High	1	0	0	1	1	1	1
E3	Very Low	0	0	0	0	0	0	1

Fig. 4. Fragments of tables assessment of the final event probable severity and the effectiveness of recovery barriers

Process of estimates is conducted using the method of fuzzy analysis of expert data [7] based on the approach of fuzzy set theory [9].

The possible damage of event and effectiveness of the barriers considered as linguistic variables (LV). Each LV has four term-sets (Table 1).

Table 1

Term-sets of linguistic variables (LV)

Term-sets of LV «Level of Damage»				Term-sets of LV «Effectiveness of Barriers»			
Catastrophic	Major	Medium	Minor	High	Medium	Low	Very Low

A number of calculations are performed based on the fuzzy ratings of experts.

a) The degree of belonging of each event to each category of possible damage calculated according to the formula

$$A_{i-m} = \frac{\sum Э_{i-m}^{j}}{N}, \qquad (1)$$

where A_{i-m} – grade of membership of the *i*-th event to the *m*-th category of damage;

$Э_{i-m}^{j}$ – expert binary rating (0 or 1) accessories *i*-th event to *m*-th categories of damage;

i – event number;

j – expert's serial number;

N – total number of experts;

m – number of categories of damage (1 – catastrophic; 2 – major, etc.).

b) The degree of belonging of the barriers of recovery of each event to each type of barriers is calculated according to the formula

$$B_{i-k} = \frac{\sum Э_{i-k}^{j}}{N}, \qquad (2)$$

where B_{i-k} – grade of membership of barriers of the *i*-th event for the *k*-th type of effectiveness;

$Э_{i-m}^{j}$ – evaluation (0 or 1) of the *j*-th expert for affiliation of the barriers of the *i*-th event to *k*-th type of effectiveness;

j – expert's serial number;

N – total number of experts;

k – efficiency of the barriers (1 – very low; 2 – low, etc.).

c) Using the results of calculations by formulas (1) and (2) the ERC indicator is calculated for each event according to the formula

$$ERC_i = \sum_{m=1} \sum_{k=1} E_m^k A_{i-m} B_{i-k},$$

where E_m^k – value of ERC indicator (from 1 to 2500) in the cells of ARMS matrix (Fig. 2) corresponding to category m of the damage and category k of effectiveness of the barriers.

MONITORING OF THE ERC INDICATOR

For weekly monitoring of ERC indicator simple moving average can be used with one quarter (13 weeks) period of smoothing.

The calculation can be performed according to the formula

$$ERC_g = \frac{\sum_{i \in G} ERC_i}{П_G} \times 1000,$$

where ERC_g – relative ERC in 1000 flights per *g*-th week;

ERC_i – ERC value for the *i*-th event;

G – set of events over the 13 weeks before the date of monitoring;

$П_G$ – number of flights over the 13 weeks before the date of monitoring.

A fragment of weekly monitoring ERC in one of the airlines for two aircraft types (A and B) shown in Fig. 5.

The screen is divided into three zones according to the "traffic light" principle.

The company had made that the boundary between green and yellow area on the monitoring screen is ERC = 100, and between yellow and red – ERC = 1000.

Monitoring allows tracking the dynamics of the level of safety in the airline. The graph in Fig. 5 shows that the level of safety of aircraft type B is significantly lower than aircraft type A. There is a red output of the ERC in August, which indicates the need for urgent action.

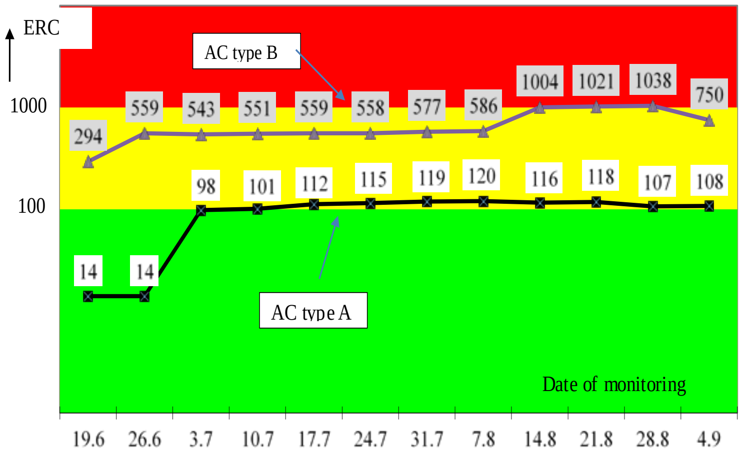

Fig. 5. Weekly monitoring of ERC by a simple moving average (logarithmic scale)

The method can be used for risk assessment for each airport, phase of flight, crew. For example, it is possible to obtain the total risk indicator of unstabilized approach ERC_{Uk}^{k} at the airport k as

$$ERC_{Uk}^{k} = \sum_{i=1}^{n} ERC_{i}^{k} ,$$

where ERC_{i}^{k} an indicator of each of the n unstabilized approaches.

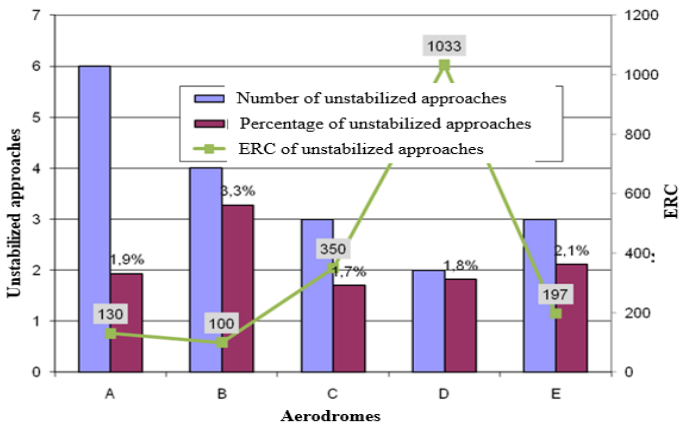

Fig. 6. Comparative risk assessment of unstabilized approach at aerodromes with ERC

The graphs presented in Fig. 6 show that the monitoring of the absolute values of the number of unstabilized approaches and their percentage of the total number of flights to this destination do not give the real picture of risk, since it does not take into account the risk of each approach.

In this example at the airport D only two unstabilized approach happened, but both were very dangerous. Accordingly, the special attention of the airline flight department should be put to preparations for flying to airport D.

CONCLUSION

The proposed method of fuzzy expert assessment with elements of the theory of fuzzy sets in relation to the event based risk assessment complement the method of ARMS Group. The method can be used not only in airlines, but in SMS of other aviation service providers too.

Carrying out this procedure at the level of the airline or other aviation service providers does not require special software and is easily realizable by the staff of division (inspection) of safety. It is obvious that for getting high-quality assessments you should invite not less than 10 qualified and experienced experts in various areas of operational activities of the airline, as recommended in [7].

As shown in [10] monitoring of the ERC indicator allows to assess the dynamics of the level of safety more reasonably than using other indicators. Usage of ERC indicator helps decision makers to prioritize measures aimed at improving safety and preventing aviation accidents.

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НЕЧЕТКАЯ ОЦЕНКА РИСКА АВИАЦИОННОГО СОБЫТИЯ

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В статье приведена разработанная авторами методика нечеткой экспертной оценки риска, существовавшего на момент произошедшего события, по матрице риска, предложенной Группой по решению проблем управления риском на уровне авиакомпании (ARMS).

Матрица группы ARMS позволяет количественно оценить такие риски только в фиксированных значениях, представленных в ее ячейках. При этом оценки риска в значительной степени основаны на экспертных заключениях, однако метода формирования оценок по совокупности мнений экспертов группа ARMS не предлагает. Применение обычных методов осреднения окончательных оценок экспертов затруднено ввиду экспоненциального характера изменения значений риска ячеек, если их рассматривать по столбцам и по строкам матрицы.

Предлагается метод оценки риска по матрице ARMS с использованием подхода, принятого при формировании функций принадлежности по экспертным оценкам в теории нечетких множеств. Такой подход позволяет максимально учесть мнения экспертов и получить более обоснованные оценки риска, не обязательно совпадающие с фиксированными значениями ячеек матрицы.

Ключевые слова: риск безопасности полетов, экспертные оценки, степень принадлежности.

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