DE GRUYTER OPEN
RIGA TECHNICAL UNIVERSITY
Transport and Aerospace Engineering
ISSN 2255-9876 (online)
ISSN 2255-968X (print)
August 2017, vol. 4, pp. 11–21
doi: 10.1515/tae-2017-0002
https://www.degruyter.com/view/j/tae

Development of an Information Database for the Integrated Airline Management System (IAMS)

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Abstract **– In present conditions the activity of any enterprise is represented as a combination of operational processes. Each of them corresponds to relevant airline management systems. Combining two or more management systems, it is possible to obtain an integrated management system. For the effective functioning of the integrated management system, an appropriate information system should be developed. This article proposes a model of such an information system.**

Keywords **– Aircraft, airline, flight safety, management system, process approach, quality indicators, quality management system.**

I. INTRODUCTION

In present conditions, the activity of any enterprise can be regarded as a set of operational processes (activity areas). Each of these processes is impacted by a relevant management system, which is developed, certified, implemented and managed in accordance with international standards. From the point of view of management system development, one of the most important principles of these standards is presentation of airline activities as a set of processes. As a result of interaction between these structures and the organized processes, there is achieved a variety of final useful results characterizing the quality of air transportation in an airline, the most important of which is flight safety. Combining two or more control systems, it is possible to obtain an integrated management system [1]–[5], [9]. For the effective functioning of the integrated management system, an appropriate information system should be developed.

II. DEVELOPING THE STRUCTURE OF THE INTEGRATED AIRLINE MANAGEMENT SYSTEM (IAMS)

An Integrated Airline Management System (IAMS) is a set of elements linked together through the **IAMS**. The IAMS should be based primarily on the quality and safety systems of an airline. The quality system is based on ISO 9000 standards [6]. The safety management system is based on ICAO requirements [7], [8]. The functions of IAMS are assigned to both flight safety and quality management. The airline information management system must consider, retain and analyse the required data set by means of an embedded algorithm, whilst at the same time meeting the requirements set out in the ICAO Safety Manual [8]. This approach is based on the identification, assessment and elimination of risks in all airline processes affecting flight safety as shown in Fig. 1.

Fig. 1. Structure of IAMS.

The basic principles of IAMS are as follows [9]:

- data collection, i.e. timely detection of deviations (risks) that can lead to special situations in flight, as well as risk level assessment;
- forecasting the trends of the effect of hazards on flight safety level;
- timely development of preventive measures, elimination or limitation of risks;
- monitoring the efficiency of such preventive actions.

Flight safety is directly proportional to the quality of an airline. The higher the quality (fewer violations, deviations), the higher flight safety (fewer risk/hazard factors, potential threats) [10]. The analysis of safety aspects is based on actual information, which may come from several sources. It is necessary to ensure the collection, classification and storage of relevant analysis data. For such an analysis, suitable analytical methods and techniques are selected and used. The analysis of safety aspects is often iterative and requires several cycles. It may be either quantitative or qualitative. The lack of basic quantitative data may cause the analyst to rely on the methods which are more focused on quality indicators. The general structure of IAMS risk management system is shown in Fig. 2.

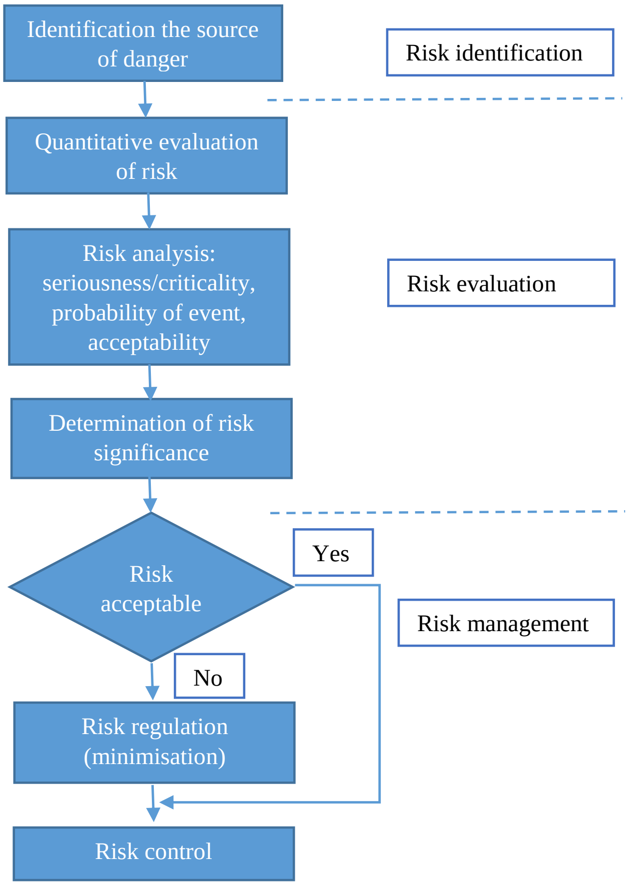

Fig. 2. Structure of IAMS risk management system.

The presence of IAMS in an airline:

- helps to increase the accuracy of integrated management;
- ensures greater coherence of processes within an airline;
- minimizes the disconnection of airline processes, which occurs due to the development of autonomous systems;
- the development and management of IAMS is less time-consuming and labor-intensive than the development of several parallel systems;
- the development of IAMS enhances corporate culture in which quality and safety are treated as equivalent basic values.

The schematic diagram of the safety management system can be represented in the form of a circuit as shown in Fig. 3. The performance of IAMS depends on the quality and capacity of each of its elements. Therefore, during the functioning of the Integrated Management System, the main workload is on the IAMS, which in itself imposes certain demands on its operation and reliability. Moreover, when assessing the approximate amount of incoming and requested information in IAMS, these requirements should be as strict as possible.

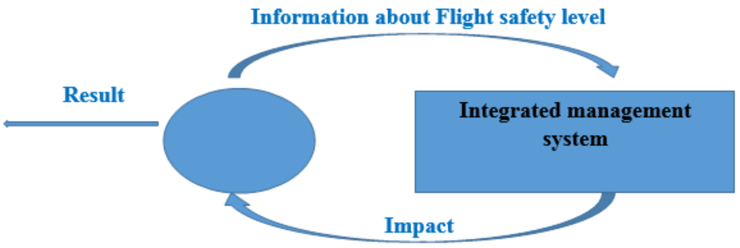

Fig. 3. A schematic diagram of the Flight Safety Management System.

III. A Methodology for the Quantitative Assessment of Flight Safety Level Ensured by IAMS

Taking into account the above mentioned facts, an airline's information management system considers and retains all the data of flight risks and hazardious events (HE) which are required for carrying out an analysis. They include the materials of accident and incident investigation, the results of decoding data from flights and inspections, anonymous reporting, the characteristics of events in special situations in flight preceding hazardious events, which include the type of specific situations, the causes, the stages of flight at which they occurred, results of audits, deviations in the performed activities and airline aviation specialists' behaviour, as well as other data.

The IAMS also includes data on performed works:

- aircraft flight hours;
- number of flights;
- number of passengers and cargo carried.

The IAMS includes data characterizing aircraft operating conditions, for example, environment (weather conditions, ornithological situation, air traffic intensity, etc.) [11]. The presentation of all data in the IAMS is differentiated by the type of aircraft, class of aircraft, type of event, phase of flight, etc. All data about hazardious events in flight represent a result of their causative analysis. In order to form a complete set of data about hazardious events, regardless of the HE (investigation, flight analysis, anonymous reporting, etc.), the scheme of their causative analysis should be unified and calculated in a way providing the possibility to study the dynamics of hazardious event development in flight. When an aircraft in normal flight mode is affected by one or more hazardious factors (risk factors), a special situation occurs. Special situations in flight are characterized by a combination of aircraft characteristics and psychophysiological parameters of pilots, which differ from normative, and a mode of flight, which differs from "regular". In the airworthiness requirements, such conditions of aircraft and crews are classified as special situations [12]. Based on this concept, five possible aircraft states can be distinguished in flight. We denote them by S_i, where $i = 0, 1, 2, 3, 4$. Normal ("regular") flight without any risk factors – S_0; Complication of Flight Conditions (CFC) – S_1; Dangerous Ssituation (DS) – S_2; Emergency – (ES) S_3; Catastrophic Situation (CS) – S_4, see Fig. 4.

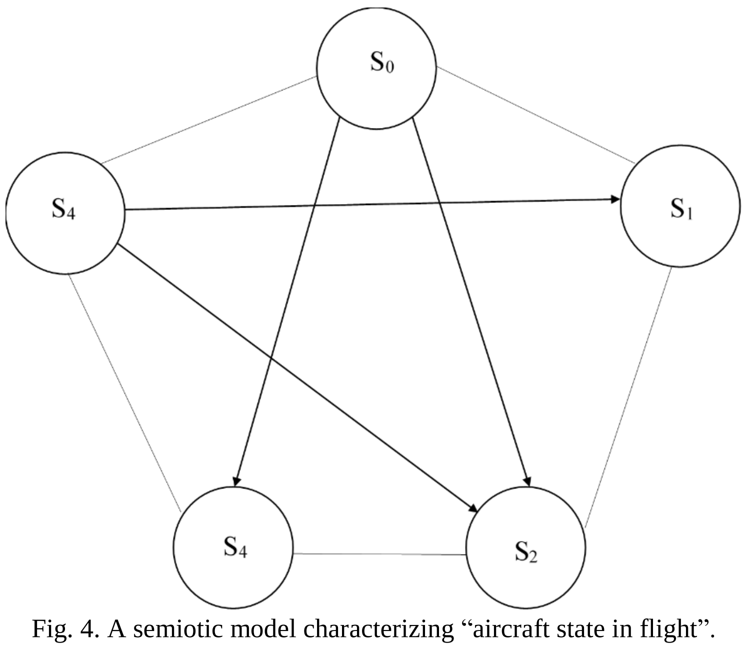

Fig. 4. A semiotic model characterizing "aircraft state in flight".

In case of a special event, a hazardious event occurs: incident or accident [3]. At the stage of analysis, the IAMS identifies the causal relationships of the development of a hazardious event, including several stages, each of which is sufficiently independent. This will determine the risk level of the hazardious event and conditions for its occurrence from the previous situation. The number of such causal chains should be equal to the number of changes in the states of the "crew-aircraft" system in flight, Fig. 4.

The IAMS software should contain mathematical laws:

- ranking of negative events;
- determining the consequences in connection with negative event occurrence;
- analysis of flight development in connection with negative event occurrence in a chain of hazardious factors;
- determining the flight outcome if several negative events occur during a short period of time;
- assessing the occurrence of this hazardious factor in connection with the occurrence of another factor and further development of the chain of hazardious factors.

The author proposes a method for calculating the dynamics of flight safety level in the IAMS through the assessment of the risk level of special events in flight in case of threat factors. To assess a risk based on the results of aircraft operations, we will use the normalized probabilities of special situations in flight [13], Fig. 4:

To detect deviations in services and airline personnel activities, we wll introduce another group of negative events in addition to the events listed above: EWDFC – event without deviations from flight normatives.

As quantitative indicators we will use:

- $P_{\mathrm{IS}}(\mathrm{O})$ – the probability of a special situation in flight caused by the appearance of a risk factor;
- $P_{\mathrm{IS}}(\sum)$ – the total probability of a special situation caused by the appearance of a risk factor. Evaluating the risk factor Q_i, let us the following condition: the appearance of hazardious factors, actions of the crew and result of the flight are accidental events, therefore the probability of a hazardious flight result, i.e. an accident, is accepted as an objective measure integrally assessing the safety level of such a flight. Further, this indicator will be called flight risk level – Q.

$$Q_i = q_i \, r_i, \tag{1}$$

where

- q_i – the probability of the i-th negative event affecting flight safety,
- r_i – the threat of the i-th negative event (probability of an aviation accident due to the i-th negative event).

Risk assessment makes it possible to rank the identified events for the groups of similar events in descending order of risk level R_i and, using the obtained sequence, to establish a priority order of measures being taken to ensure flight safety. According to this formula (1) the level of risk is assessed over a period of time $[t_0 + \Delta t]$, where t_0 is the time of hazardious factor appearance; Δt is the period of time during which the crew is taking actions for eliminating the hazardious factor. For the assessment, we will use the airworthiness requirements for ranking the probability of special situations; and out of all possible risk factors we will consider only equipment mulfunction, Fig. 5.

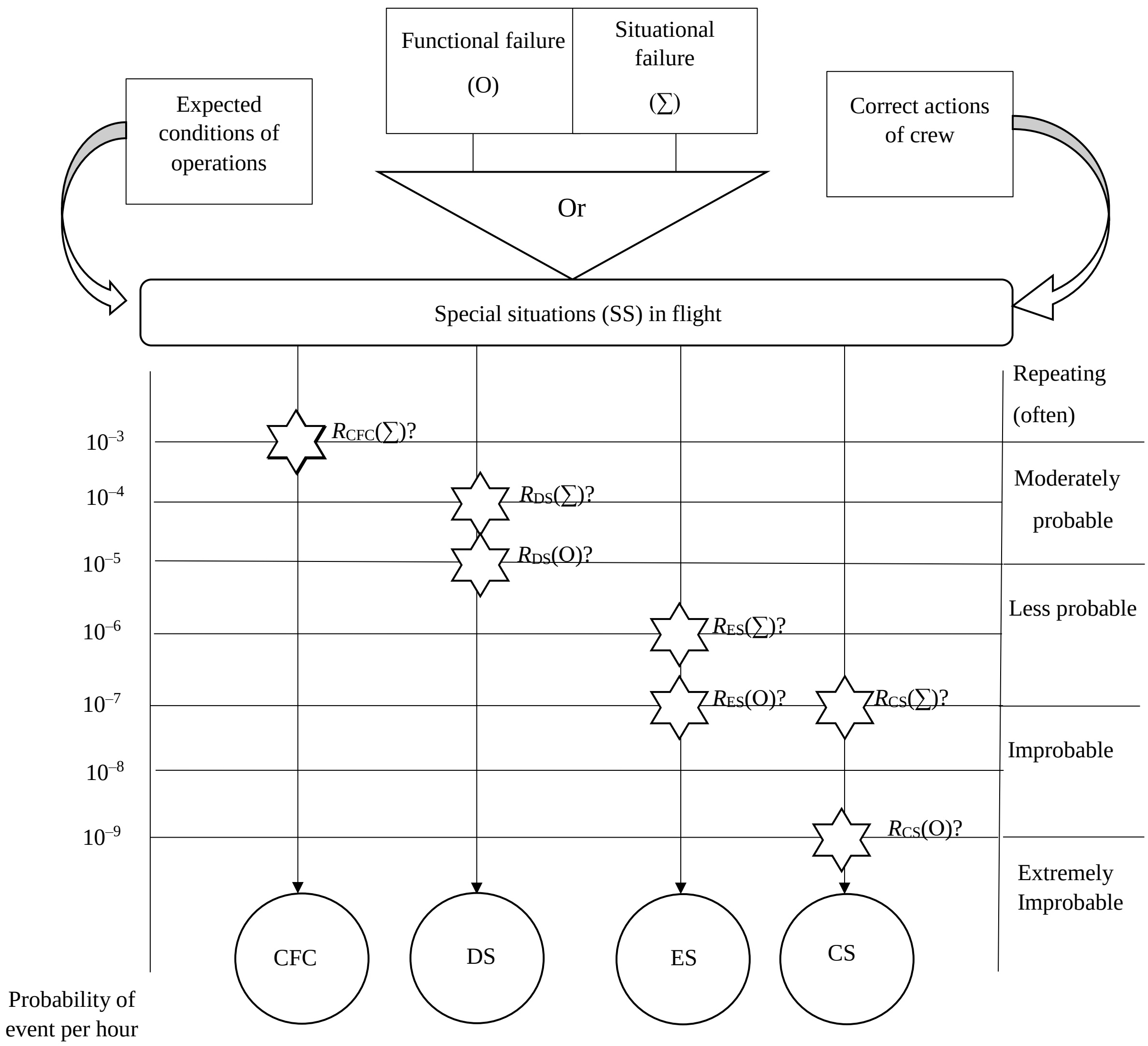

Fig. 5. Airworthiness requirements for the functional reliability of aviation equipment.

Classifying negative situations in flight in accordance with the airworthiness requirements and assuming the probability of an accident as 1, we will have:

$$Q_i = r_i\, q_i, \quad q_i = n_i / T, \tag{2}$$

where

- Q_i – event risk,
- i – special event index in flight,
- q_i – event probability,
- n_i – number of specific events occurred during the observed time interval,
- T – observed time interval.

In accordance with the airworthiness requirements, the threat level of special situations in flight has the following values: [14], [15].

$M = 10^5$ – scale coeficient of the criteria

The data on all events and their quantitative values are presented in Table I.

TABLE I

THREAT OF AN ACCIDENT FOR A CERTAIN TYPE OF EVENT

i **Index of event**	**Type of event**	***Q_i*** **Threat of accident**	***n_i*** **Number of controlled *i*-th type of events**	***T***
1	**EWDFC**	$Q_1 = 10^{-5}$	n_1 – number of controlled type of events **EWDFC**	
2	CFC	$Q_2 = 10^{-4}$	n_2 – number of controlled type of events CFC	
3	DS	$Q_3 = 10^{-3}$	n_3 – number of controlled type of events DS	
4	ES	$Q_4 = 10^{-1}$	n_4 – number of controlled type of events ES	
5	CS	$Q_5 = 10^{0}$	n_5 – number of controlled type of events CS	

To evaluate the risk level of EWCFC-type event, it is proposed to use expert assessments in situations when it is impossible to use any other mathematical technique for this purpose. In its final form, the full risk assessment per one hour of flight or one flight is determined by the following sum:

$$R / T = (Q_{CS} + Q_{ES} + Q_{DS} + Q_{CFC} + Q_{EWCFC}) / T = (\Sigma q_i\, r_i) / T. \quad (3)$$

According to ICAO recommendations, the pyramid of conditional repetitions "1 : 10 : 30 : 600" (the conditional ratio of the frequency of negative events in flight) is used to calculate the quantitative values of negative events in flight, Fig 6.

$$n_C : n_A : n_{SI} : n_I = 1 : 10 : 30 : 600, \quad (4)$$

where n_C – number of accidents, n_A – number of crashes, n_{SI} – number of serious incidents, n_I – number of incidents.

Using this rule, let us refer to a pyramid of conditional repeatability of special events including **EWDFC** events – "1 : 10 : 100 : 10 000 : (>10 000)" (the conditional ratio of repeatability of special events in flight), Fig. 6.

$$n_{CS} : n_{ES} : n_{DS} : n_{CFC} : n_{EWCFC} = 1 : 10 : 10^2 : 10^4 : (>10^4), \quad (5)$$

where n_{CS} – number of accidents, n_{ES} – number of emergency events, n_{DS} – number of dangerous events, n_{CFC} – number of events with complicated flight conditions, n_{EWCFS} – number of events without complicated flight conditions.

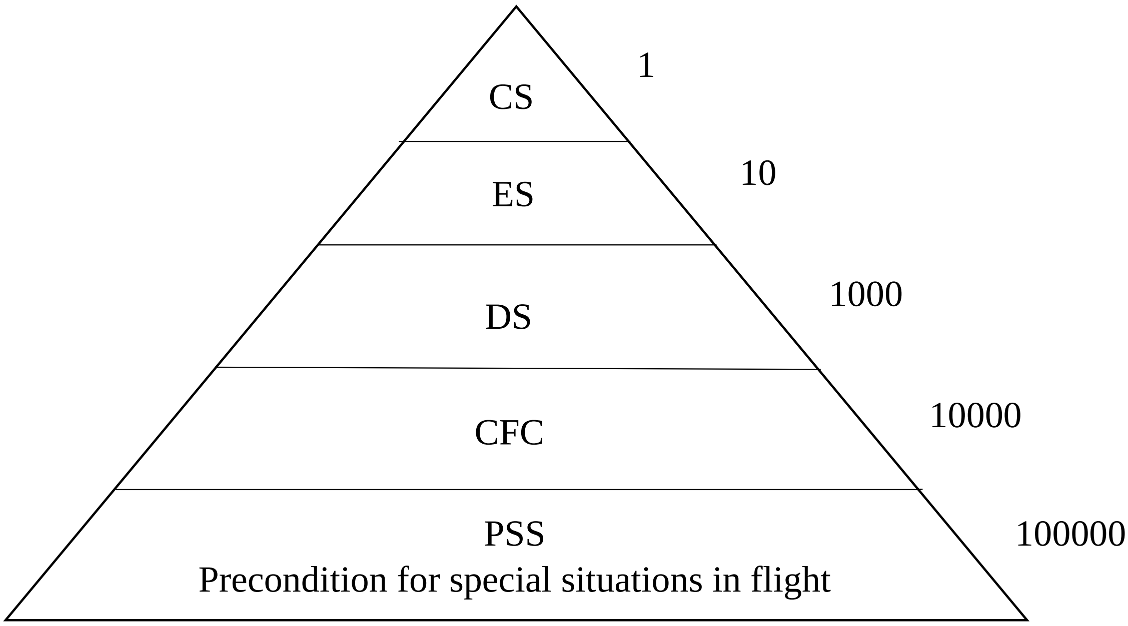

Fig. 6. Pyramid of repeatability of events in flight.

Here CS – catastrophic situation; ES – emergency; CC – dangerous; CFC - complicated flight conditions.

In our case, it is proposed to use the whole arsenal of special situations to assess the level of risk. Then the risk level *R* will represent the sum of the risks of special situations that can arise as a consequence of factors embedded at the bottom of Fig. 6 through the weighting factors λ_i:

$$R = (N_{ks}\lambda_{ks} + N_{as}\lambda_{as} + N_{bs}\lambda_{bs} + N_{las}\lambda_{las} + N_{blas}\lambda_{blas}) = \sum^{n}_{i=1}(N_i\lambda_i), \qquad i = 1, \qquad (6)$$

where N_{ks}, N_{as}, N_{bs}, $N_{las,}$ N_{blas} – number of accidents, emeregncy, dangerous situations, complicated flight conditions and events without the complication of flight conditions;

λ_{ks}, λ_{as}, λ_{bs}, λ_{las} , λ_{blas} – severity of different types of special events.

The use of special events for the assessment of hazards in the IAMS of an airline makes it possible to create a specific hazard scale. It should be taken into account that such a scale needs periodic re-grading, since the actual values of λ are determined from the achieved safety level, which changes with time. Moreover, in relation to different hazard factors, λ can differ significantly. And this circumstance should also be taken into account in the formula for *R*, for example, by dividing risk factors into three categories:

- Human factor.
- Equipment failure / Technical factor.
- Hazardios environmental factor.

The formula (6) will look like this:

$$R = [(N_{cs}^{C} \cdot \lambda_{cs}^{C} + N_{cs}^{T} \cdot \lambda_{cs}^{T} + N_{cs}^{V} \cdot \lambda_{cs}^{V}) + ... + (N_{swcfc}^{C} \cdot \lambda_{swcfc}^{C} + N_{swcfc}^{T} \cdot \lambda_{swcfc}^{T} + N_{swcfc}^{V} \cdot \lambda_{swcfc}^{V})], \qquad (7)$$

where “h”, “T”, “C” mean “human factor”, “Equipment failure / Technical factor”, “environment”.

When creating a hazard scale, it is assumed that all possible values are in the interval “0” to “1”, representing the lower and upper boundaries. The subsequent graduation of the scale is equivalent to the procedure for assessing the hazard of special events. The numerical values of λ_i can be established a priori on the basis of using a system of differentiated equations. However, the most acceptable way of determining the numerical values of weighting coefficients is statistical data. It involves the determination of the frequency of the transition of emergency, dangerous events and complicated flight conditions into an accident [14]–[17]. For this purpose, it is necessary to take into account both the absolute values of different kinds of special events that occurred within the estimated time and their components equal to the number of transitions to this situation from the preceding situations, Fig. 6. This is a very complex process and it makes sense to develop such an approach to generally assess the risk of flight hazards to a transport system [18]. For an individual airline with a small and medium number of flights, the relative flight safety index can be estimated with sufficient accuracy by the formula:

$$k = N_{NG} / A, \qquad (8)$$

where:

- N_{NG} – total number of negative events classified by the regulatory documents, as well as the existing inconsistencies and violations of the standardized parameters, established rules and requirements of the guidance documents, equipment failures and other events which do not fall under these events (the bottom of Fig. 6) [13], [15];
- *A* – the amount of useful work performed by an airline during a certain period.

For *k*, the condition $k < 1$ is fulfilled. To increase the sensitivity of the relative criterion of flight safety, we will introduce:

$M = 10^4$ – scale coefficient of the criteria

N_{NG} is calculated by the formula:

$$N_{NG} = K_1N_{ks} + K_2N_{es} + K_3N_{ds} + K_4N_{cfc} + K_5N_{swcfc}, = \sum^{n}_{i=1}(N_iK_i),\ i = 1, \qquad (9)$$

where

- K_1, K_2, K_3, K_4, K_5 – factors of negative aviation events. According to the meaning of these factors they correspond to the coefficient λ_i (7);
- N_{cs} – number of accident situations during a certain period;
- N_{es} – number of emergencies during a certain period;
- N_{ds} – number of dangerous situations during a certain period;
- N_{cfc} – number of complications of flight conditions during a certain period;
- N_{swcfc} – number of situations without any complication of flight conditions during a certain period.

Negative events differ from each other not only by the level of risk posed by their consequences but also by the frequency of their occurrence during an airline's operation. Thus, the coeficients of events can be determined with the help of the expert method.

$$K_1 = 0.5,\ K_2 = 0.3,\ K_3 = 0.1,\ K_4 = 0.05,\ K_5 = 0.005. \quad (10)$$

By using the previous formulas, we can get the following formula:

$$K = (0.5N_{cs} + 0.3N_{es} + 0.1N_{ds} + 0.05N_{cfc} + 0.005N_{swcfc})10^4 / A. \quad (11)$$

To calculate the level of flight safety in an airline for the analysed period of time, the following formula should be used (12):

$$K = (1 - N_{NG} / A)\ 100\%. \quad (12)$$

The evaluation range is shown in Table II:

TABLE II

RATIONING OF RELATIVE STATISTICAL SAFETY CRITERA FOR AIRLINES

[100–99.99] %	High level of flight safety
(99.99–99.98] %	Acceptable level of flight safety
(99.98–99.97] %	Low level of flight safety
(99.97–0] %	Threat to flight safety

IV. CONCLUSION

1. The airline information management system should consider, retain and analyse the required data, work with all hierarchical levels of events represented through the embedded algorithm, whilst at the same time meeting the latest ICAO safety requirements [19].
2. The effective management of an airline requires analytical skills which the management may not always have to apply in everyday work. The more complex the analysis, the more pressing the need to use the most appropriate analytical methods. For the closed cycle of the management process, it is required to have a feedback allowing the administration of an airline to verify the correctness of decisions and evaluate the efficiency of their implementation. The IAMS system can become a reliable tool for solving these problems.
3. In our opinion, the proposed method for the quantitative assessment of flight safety level included in the IAMS is easy to understand and form. It takes into account the amount of useful work performed by an airline (air transportation) as well as all the factors of possible negative events in an airline.

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