

ALGORITHM FOR ANALYZING DEVIATIONS AND IRREGULARITIES IN THE FUNCTIONING OF THE AIRLINE'S STRUCTURAL UNITS AND PERSONNEL IN THE FACE OF UNCERTAINTY

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Abstract. At the heart of airline flight safety management is a systematic approach to identifying hazards and controlling risk factors, which ICAO requires to collect, analyze all deviations in the activities of units, services and personnel airlines and use of its results to develop and implement management activities. That kind of the system enables the organization to predict and fix problems before they lead to an aviation accident. Thus, the organizational management structure should ensure high efficiency, reliability and completeness of the control over all components that ensure the process of the air transportation: the course of transportation, the clear operation of all units in the uninterrupted transport process and their correct matching. In modern conditions, this result is achieved based on a process approach, when the company's activities are presented as a set of production processes (activities). For each of these areas, the airline has appropriate management systems that are developed, certified, implemented and operated in accordance with international standards. As a result of the interaction of these processes, the goals of the aviation enterprise, which determine its competitiveness, are achieved.

Keywords: flight safety, aircraft, risk, algorithm, accident failure, faulty condition, flight delay, management.

Introduction

Multifactorial causes of accident and cause-and-effect of events in flight are an important issue. Usually it is a combination of several different factors related to the crew activity, the functional efficiency of the armed forces – especially in the event of an attack on an aircraft (Gapiński & Stefański, 2014a, 2014b; Stefański et al., 2014), the conditions of the external environment. In the process of developing a negative phenomenon, which ends with an aviation accident, in most cases there may be several reasons that consistently complicate the situation and eventually lead to the accident. Thus, the aviation accident is mostly complex and is a closing in the chain of successive events with causal and investigative relationships (Ale, 2002). By tracking the sequence of the adverse event, the following categories of causes can be identified: major, immediate and contributing. The main one is the reason that this situation creates a potential for an accident. Immediate and contributing are the reasons that create real conditions for the transformation of opportunity into reality.

Thus, the immediate cause is the one that entails an aviation accident as a result of friction (Żórawski et al., 2008; Góral et al., 2013) or fatigue (Chatys & Koruba, 2005) in various constructions (Chatys, 2013; Majewski et al., 2017), not only traditional but composite materials. Usually it is the result of the main reason. One of the main reasons is the organizational activity that has developed in the airline, which causes deviations and disruptions in the functioning of its elements (International Civil Aviation Organization, 2007, 2016; ISO, 2016; IOSA Standard Guide, 2012). By the inconsistency in the work of personnel we will understand errors that have led to or may lead to the loss of the system of “crew-aircraft” properties, perform the assigned functions and thus, create a risk of the occurrence of special situations in flight and when they occur implementation, an accident or an incident in flight (Gorbachev et al., 2019; Bogdane et al., 2019). The analysis of flight safety-affecting deviations and irregularities in the operation of elements of the airline is an integral part of the decision-making procedure of the management of the

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airline, its services and units. In the implementation of this procedure involved specialists of different categories and specialties, who before making any management decision must collect and process information about the object of management (OM), make a judgment on the condition of the object, compare this state with the accepted model, identify contradictions in this comparison and formally identify a set of intended actions from which to choose one or more of the highest priority. At each of these stages of decision-making, an analysis is needed: completeness and quality of information about the OM, the state of the OM, the adopted model of the OM, the results of comparing the OM with the model, the intended set of actions and the consequences of their implementation. The versatility, multivariability, multi-criteria and uncertainty of different situations in the airline, greatly complicates the task of forming an algorithm to analyze deviations and violations on flight safety. At the same time, two areas of analysis need to be identified: analysis of deviations and violations in order to identify their effects on the flight safety and analysis of the causes and factors that led to deviations and violations in order to develop measures to prevent them. Deviations and violations can have a direct impact on a flight safety by disrupting the airworthiness (Bielawski, 2015) of the main elements of the aircraft, indirect impact through a decrease in the functional efficiency of the individual elements of the airline, or their totality, may also be in a situation where the negative impact is manifested in the presence of additional factors. The causes of deviations and violations can be human made, technological (Żórawski et al., 2008) and environmental impacts, shortcomings in the organization of aviation specialists and the operation of aviation equipment, and much more. Both, the first and second areas of the analysis of the impact of deviations and violations on the flight safety, are among the areas of a factor analysis of the organizational systems. The main tasks of the factor analysis are divided into two classes: the tasks of a deterministic analysis and task of the analysis in conditions of uncertainty (Shestakov, 2012).

1. Algorithm for analyzing deviations and irregularities in the functioning of the airline's structural units and personnel in the face of uncertainty

A significant factor in improving the scientific level of governance in the flight safety and security system is the use of mathematical methods and models in the preparation of solutions. However, complete mathematical formalization of processes in the aviation system is practically impossible because of the diversity and complexity of its elements and factors that affect its functioning. In this regard, it seems appropriate to use approaches based on the theory of semiotic systems (Vinogradovs et al., 2010; Shestakov et al., 2019). This approach based on semiotic systems theory adequately describes the problems that are characterized by a complex structure. On the other

hand, the model based on semantic theory is a convenient means for formalizing the problem under consideration – using the appropriate mathematical apparatus can solve this problem analytically. We apply this approach in the development of an algorithm to analyze deviations in conditions of uncertainty.

The factor analysis in the face of uncertainty is characterized by the absence of a clear form of analytical dependence of system indicators of various factors, with sufficient representative statistics of factors, indicators and events in the airline. The tasks of the deterministic factor analysis involve the analytical relationship between factors, indicators and events. The facts, indicators and events themselves are defined. Solving both tasks involves:

1. The organizational structure of the system with functional and informational links between the elements;
2. A combination of indicators or factors (system databases) organized in a certain way;
3. Specialists trained to analyze and to make decisions and have the proper authorization;
4. Statistical material on deviations and irregularities in services and units;
5. Mathematical methods and models for processing information about the functioning of the AC;
6. Technology and computing equipment to provide analysis and decision-making;
7. Criteria for assessing the impact of deviations and violations on flight safety;
8. Criteria for assessing the effectiveness of the measures developed and the costs of implementing them.

A generalized algorithm for analyzing deviations in the functioning of airline elements in order to develop measures aimed at increasing the level of flight safety, in view of its cumbersome nature, is not given in the article. Its main provisions are as follows. This algorithm uses the manager's method of phasing out a deviation as an event. As a general feedback, the presented algorithm is supposed to monitor the implementation of the measures taken to eliminate the consequences of the event and prevent its occurrence, monitoring the state of the element of the system after the implementation of the measures, the presented algorithm assumes control over the implementation of measures taken as a basic feedback in order to eliminate the consequences of the event and prevent them, monitor the state of the system element after the implementation of measures. The algorithm is built with the limited powers of a leader and the ability to involve a higher-level manager in the analysis and the decision-making process. The "inclusion" of a superior leader in the analysis scheme is possible at any stage, and he can be satisfied with the activities of the subordinate and continue the analysis from the outset. The algorithm also provides a lack of competence of the manager or indecision in performing certain stages and the ability to attract colleagues, more qualified professionals, specialists of other services, etc., united in the scheme called "experts" to solve individual analysis problems. We proceed from the conditions

that the system of risk management associated with deviations in the airline's activities solves the problem of reporting to an acceptable level of their impact on flight safety. Based on the conditions, the risk management system associated with deviations in the airline's activities solves the problem of reducing its impact on the flight safety to an acceptable level. Once the deviations have been identified, the associated risks and the nature of the risks examined for "acceptable or unacceptable" risks should be assessed. If the risk is "unacceptable", appropriate measures, including the determination of individual guilt, must be taken. The analysis scheme provides the rapid action against the event and the ability to consider the event and activities associated with it. The proposed algorithm can be used in the creation of an automated expert system for analyzing relationships in the functioning of airline elements.

2. Method for calculating the relative criterion of the airline flight safety

The safety of flights in an airline is directly proportional to the quality of operation of its individual elements (services, departments, personnel). The higher the quality (less violations, deviations), the higher the safety of flights (less risk/hazard factors, potential threats). It is generally believed that in aviation, depending on the severity of the consequences, there are four types of negative events (Bogdane et al., 2018; Vaivads et al., 2018):

1. Catastrophe – is an event with human casualties;
2. Accident – is an event characterized by the complete loss of an aircraft or requiring major repairs, but without human casualties;
3. A serious incident – is an event characterized by real danger;
4. An incident – is an event characterized by a manifestation of potential danger.

Negative events are the result of the realization of special situations in flight that occur when one or more adverse factors are exposed to an aircraft (Bogdane et al., 2016). There can be four such situations in flight according to the classification of the Airday Standards:

1. CS – Catastrophic situation;
2. ES – Emergency situation;
3. DS – Difficult situation;
4. CFC – Complicated flight conditions.

The authors propose a method of calculating the relative criterion of flight safety, considering the quality of the airline's operation. Taking into account possible deviations in the activities of services and personnel and not leading directly to special situations during the flight, we will introduce an additional emergency situation in flight. We will designate them as a PSS (preconditions of special situations). The analysis of the structure of services and information flows on safety showed that the main documents in the process of identifying deviations in the activities of services and personnel in the performance of flights are:

1. Journey Technical Logs (Logbooks).

2. Work Orders with damage checks task cards.
3. Flight Data Monitoring (Results of the monitoring performed during aircraft systems use the flight information).
4. Pre-Flight Daily/Weekly check task cards (Inspections performed).
5. Minimum Equipment Items List.
6. Incident Investigation Acts.
7. Engine Health Monitoring Data and Engine Run Test Data (Acts of measurements of engine operational parameters).
8. Flight Chart Cards.
9. Operational Control Center Records (Workshop Manager Logs).
10. Journal of the Technical Analysis. Safety Records, Technical Occurrence Survey Data.
11. Reliability data reports.
12. The Results of the Control Technology Piloting. Flight Data Monitoring Records.
13. The Results of the Control checks of the Crew during the Flight by Officers of the Flight Staff. Crew Line Operation, Safety Checks, Line checks, Qualification Check Records.
14. Ground and on-Board means of Collecting Flight Information (Flight Data Monitoring, Cockpit Voice Communication (Cockpit Voice Recorder)).
15. Results of the Control Checks and Crew Training in Complex Simulators Flight.
16. Journal of Briefing and Analysis of the Flight Manager Change.
17. The Logbook of Special cases, Incidents. Flights Safety Reports with the Investigation Records.

Then the relative measure of flight safety in the airline, k can be determined by the formula:

$$k = \frac{N_{MS}}{A}, \quad (1)$$

where: A – total number of flights; N_{MS} – the total number of flights with the non-normal situations (special situations and preconditions). N_{MS} is determined by formula:

$$N_{MS} = K_1 N_{CS} + K_2 N_{ES} + K_3 N_{DS} + K_4 N_{CFC} + K_5 N_{PSS} = \sum_{i=1}^n (N_i K_i), \quad (2)$$

where: K_1, K_2, K_3, K_4, K_5 – weight coefficients of negative aviation events.

All possible values lie in the "0"–"1" interval and can be established antecedent using a system of differentiated equations or through the method of expert evaluations. However, the most appropriate way to determine the numerical values of weights remains a statistical estimate. It is to determine the frequency of emergency transition, difficult situation and complication of conditions in a catastrophic situation. For this purpose, both the absolute numbers of the amount of different special situations that occurred during the estimated time and their constituents should be taken into account, equal to the number of transitions to this situation from the situations preced-

ing it. This is a very complex process and it makes sense when developing such an approach to assess the risk of flying in general to the transport system. For a single airline with small and medium air traffic, the relative safety rate of flights for the estimated period can be assessed with sufficient accuracy using the pyramid of conditional ratio of repetitiveness of the non-normal situations during the flight in the form of Figure 1. Here the N_{CS} is the number of catastrophic situations, N_{ES} – the number of emergencies, the N_{DS} – the number of complex situations, the N_{CFC} – the number of situations complicating flight conditions, N_{PSS} – the number of prerequisites for special situations of flight. In this case, we get a ratio:

$$N_{CS} : N_{ES} : N_{DS} : N_{CFC} : N_{PSS} = 1 : 10 : 10^2 : 10^3 : 10^4. \quad (3)$$

Based on the pyramid of ratios, we will have: $K_1 = 0.1$; $K_2 = 0.01$; $K_3 = 0.001$; $K_4 = 0.0001$; $K_5 = 0.00001$.

Another option for assessing these ratios may be the method of expert assessments. Putting values from (2,3) into the formula get:

$$k = \frac{0.1N_{CS} + 0.01N_{ES} + 0.001N_{DS} + 0.000N_{CFC} + 0.00001N_{PSS}}{A}, \quad (4)$$

where: N_{CS} – number of catastrophic situations over the estimated period; N_{ES} – number of emergency situations during the estimated period; N_{DS} – number of dangerous situations during the estimated period; N_{CFC} – number of complications of the flight conditions during the estimated period; N_{PSS} – number of preconditions for the special flight situations over the estimated period.

3. Quantitative assessment of the level of safety using the concept of risk

To assess the level of safety, it is proposed to use the ICAO pyramid (ISO, 2016; IOSA Standard Guide, 2012), which is known in aviation and which characterizes the ratio of various events, adding to them another level, called BSLA (an event without complicated flight conditions “normal”) which can occur as result of another negative events during the operation of the airline (Figure 1). For the small and medium size airlines which have integrated management system, the relative flight safety indicator can be calculated with sufficient accuracy using the following formula:

$$k = \frac{N_{NG}}{A}, \quad (5)$$

where: N_{NG} – total number of negative events classified in the normative documents, as well as the violations of existing irregularities and standard (specified) parameters, equipment failures and other events not falling within the pyramid events shown in Figure 1, such as passengers, flights, landings, etc.; A – aircraft flown hours during the calculated period of time.

Condition of coefficient K correspond to the measure $k < 1$.

In order to increase the relative level of flight safety, we introduce the criterion scale factor:

$$M = 10^5. \quad (6)$$

N_{NG} is calculated according to the following formula:

$$N_{NG} = K_1N_{ks} + K_2N_{as} + K_3N_{ss} + K_4N_{sla} + K_5N_{bsla} = \sum_{i=1}^n N_i K_i, \quad (7)$$

where: K_1, K_2, K_3, K_4, K_5 – the weight factor of negative events.

The negative event weight coefficients (K_1, K_2, K_3, K_4, K_5) correspond to coefficients obtained from formula (3):

1. N_{ks} – number of catastrophic situations during the calculation period;
2. N_{as} – number of emergency situations during the calculation period;
3. N_{ss} – number of complex situations in the calculation period;
4. N_{sla} – number of complex flight conditions in the calculation period;
5. N_{bsla} – number of events without complicated flight conditions during the calculation period.

Weighting factors can be established on the basis of the ICAO pyramid, using expert method or using a combination of them. Based on the latter method, the authors obtained weight coefficients in the form:

$$K_1 = 0.5; K_2 = 0.3; K_3 = 0.1; K_4 = 0.05; K_5 = 0.005. \quad (8)$$

In this case, the safety factor in the airline during the analyzed period will be:

$$k = \frac{(0.5N_{ks} + 0.3N_{as} + 0.1N_{ss} + 0.005N_{bsla})}{A} \cdot 10^5. \quad (9)$$

At the same time, on the basis of the requirements of ICAO and the Aviation Authority, the airline sets its permissible safety margin for a fixed period, k_b (Table 1). Its value will be set for each subsequent period depending on its actual values in the previous, accounting period.

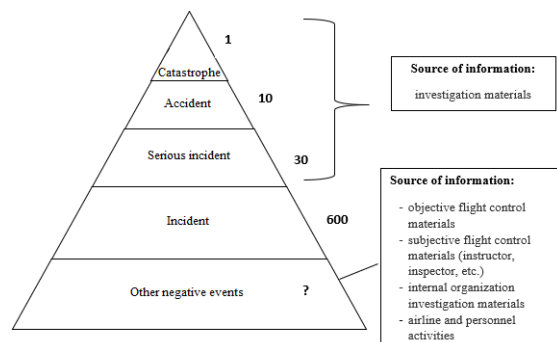


Figure 1. ICAO event pyramid supplemented (ISO, 2016)

Table 1. Flight Safety Indicators in the airline

Year	2014				2015				2016				2017			
Quarter	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
N_{NG}	1.1	1.2	1.4	1.1	0.9	1.4	1.3	1	1.2	1.7	2.4	1.8	2	0.7	0.7	0
A	401	483	529	443	564	579	408	435	612	758	750	568	618	617	650	0
$k \cdot 10^{-2}$	0.274	0.248	0.265	0.212	0.203	0.248	0.225	0.245	0.276	0.278	0.317	0.242	0.352	0.115	0.109	0
$k_b \cdot 10^{-2}$	0	0	0	0	0.209	0.209	0.209	0.209	0.209	0.209	0	0.254	0.246	0.228	0	0

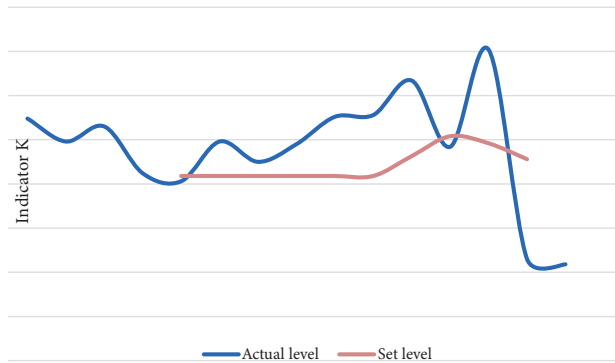


Figure 2. The change in the flight safety indicator of the airline by year

The relative indicator of safety (k_r) also can be used which is defined as:

$$k_r = \frac{1 - N_{NG}}{A} \cdot 100\% . \tag{10}$$

The relative safety indicator k_r in a given time period is simple and easy to understand.

This index takes into account the workload of the airline, all the negative events of the airline and reflects the level of flight safety.

A fragment of the calculation according to the proposed methodology for the flight safety Indicators of an airline operating charter flights for a certain period is presented in Figure 2 below and in Table 1 below.

As can be seen from the graph below (Figure 2), during 2014 and the beginning of 2015, safety in the airline tended to improve and for 2015, the acceptable safety factor was set to $k_b = 0.00209$. However, due to a number of reasons, since the first quarter of this year, safety began to deteriorate due to poor management, reaching a maximum by the beginning of 2017. The management of the airline took a number of measures, including the introduction of positive safety in the services and among the personnel of the airline, and safety accordingly improved dramatically. Therefore, the normative safety indicator was firstly established as $k_b = 0.00254$. In the following quarters, safety indicator became more strict taking into account the fact that actual safety has improved.

Conclusions

1. The proposed methods for assessing the safety of an airline based on a risk assessment are such that it provides a more objective assessment compared to traditional (statistical) methods used at national or industrial level, as it takes into account not only incidents and more serious incidents but all hazards that may arise in any airline. It allows for systematic analysis of even minor deviations from established procedures and measures to prevent them, thus reducing the risk of accidents.
2. Our method of evaluating the level of safety allows us to identify and eliminate hidden deficiencies based on the well-known ICAO pyramid.
3. According to the calculations, the airline does not have the required level of flight safety, which requires to improve system for collecting information on hazards and developing more effective measures to eliminate them and, thus mitigate risks.

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