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Risk Assessment of the Adverse Events in Air Transportation

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***Abstract* – In the field of security in transport distinguish risks related to flight safety and aviation security. Safety of flights is ensured through the reliability of aviation equipment and the qualification of the personnel who services and operates it, aviation security is a condition of protection from illegal interference in its activity. Risk management in civil aviation in the field of security is a relatively new direction of activity. Deep research in this area began only at the beginning of the XXI century. It is quite difficult to use the existing experience of risk management, accumulated in other spheres, as civil aviation has significant features. Various methods and schemes can be used to assess risks. The article discusses various options for predicting risks using the "event tree" and "risk factor tree" methods.**

***Keywords* – Aviation security, "event tree", flight safety, risk assessment.**

I. Introduction

Taking in consideration the growth of the volume of air transportation, a widespread renewal of the airplanes and a generational change of aviation specialist, necessity of solving the problems related to a safety on the air transportation appeared on the new level at the current moment of development of aviation. After conducting deep researches of air transportation and the industry of aviation, the International Civilian Aviation Organization (ICAO) concluded that the most effective way to improve flight safety is an implementation of systematic approach in the managing of safety on the bases of the risks. Moreover, there are different risks: related to the flight safety and aviation safety. Flight safety (FS) is a complex characteristic of air transport and aviation service that define an ability to fulfil a flight without a threat to the life or health of people. Maintaining the flight safety of the aircrafts is complicate task that is solved by common effort of producers of the civil aircraft and the individuals who operate this equipment. It is right to say that flight safety is achieved by reliability of the aircrafts and qualification of personal that maintain and operate it [1]. ICAO defines flight safety as "the state of aviation system in which the risks associated with aviation activities are reduced and controlled on acceptable level" [1]. Therefore, the main tasks of maintaining flight safety of the Air Company are development of the measures for analyse, evaluation and implementation of the procedures that reduce the risks to an acceptable level and there is an ability to control them. This requirement of ICAO came in to the force in 2013. An aviation safety (AS) is a state of aviation protection from unlawful interference in its work. Aviation safety is achieved by complex of measures, which involves the founding and functioning of aviation security service, protection of the airports, airplanes and objects of civilian aviation; efficient clearance of passengers, crews, baggage, cargo and mail; prevention and suppression of attempts of seizure and hijack of the airplanes [2], [3]. Therefore, in this case we can say that an aviation safety is "the state when the risks of an unlawful interference in any of above-mentioned components that may be harmful, are decreased to an acceptable level and controlled". It means that to increase an effectiveness of functioning system of aviation safety we can take full advantage of use the methods, that are applied for increasing a level of aviation safety, of identification an analyse, evaluation and implementation of the measures that will decrease the risks to the acceptable level and could be controlled. However, there are not enough references in ICAO documents to build effective system of flight safety on the level of Air Company. Under these circumstances each air company is looking to solve the problems by developing their own methodology and tools of implementation. Furthermore, specialists derive experience from the development of safety system in other dangerous industries or the leading world's Air Companies [4]. The risks management in the civil aviation in the area of flight safety is relatively new range of activities. The deep research started only in the beginning of this century [5]. The use of an existing experience from other domains is difficult because the civil aviation has its own following specifics:

- Extremely complicated systems of air transport (SAT);
- High level of uncertainty during the influence from external danger factors, either natural or artificial;
- The specific and diverse role of human in civil aviation;
- Global scope of civil aviation activities.

This implies a certain specificity in the use of the concept of risks in aviation safety issues.

II. A Risk as a Threat Measure of the System of Air Transport (SAT)

In modern terminology exist many definitions of a risk. All of them have conclusion that a risk includes probability of damage and a range of that damage. In other terms, if there are highest probabilities of happening one or other event, and the more damaging consequences would occur, the higher level of risk exists.

Using an aircraft, individuals spend there some period of his life, i.e. time. In doing so they risks they life and health. At the same time, an adverse event in civil aviation also contribute material damage and/or damage to an environment. Therefore, damage can be measured not only in the material terms. It can be fixed decrease of safety of vital activity, inability to maintain flight safety, decline of concurrency, etc., it means that this subject is related with a risk of socio – economic harm for human, enterprises and society. It can be calculated with the following formula:

$$R = Q_{ni} \times Y_{ni} \quad (1)$$

Q_{ni} – probability of i – specific situation, related to the condition when level of safety decreasing due to the unfavourable factors. Meantime a level of the threat can deviate from complication in functioning of the system to the catastrophic level, when rescue of the individuals and/or material assets become equal to the practically impossible value [6].

Y_{ni} – the level of a threat in the specific situations that is evaluated as a scope of damage: fatality or seriousness of human injuries, devastating and/or damage of material assets, harm to the environment. Both indicators of risk are reflected in frequency or probabilistic characteristics during the certain period (e.g. – year).

Representation of the risk of air transportation process by the risk of socio-economic harm makes it possible simultaneously determine both the coincidence of adverse events and inevitability of the damage in the same units, also costs of prevention.

Information about the all causes of the damage, before the unfavourable conditions happen, gives possibility to adapt a single mechanism of its origin in the process of foundation and development of event as a transition of special situation from less to more hazards. Interference of organizations and individuals who are involved in the minimization and prevention of unfavourable consequences are taking in consideration during this process.

Such approach would enable evaluate the parameters, that is part of (1) and predict a risk. The ability to predict a risk of socio-economic damage makes real the process of safety maintenance on the air transport. The aim of it is minimization of total cost of objective and subjective existence of hazards, for example in the airport. Exist different methods of evaluation of indicator Q_{ni}. We are suggesting the method of evaluation of indicator Y_{ni}.

III. The Methods of Risks Evaluation

For evaluation of the risks, different methods and schemes can be used [7]. More often air companies use the Automated Systems (AS) for prediction and prevention of air incidents, where

“Event Tree” and “Risk Factor Tree” are used to define the indicator of flight safety. Event Trees are the graphic models that streamline and display the process of unfavourable event. Such approach is legitimized by the standard ICO-9004-4 (1993) [8]. Methodology of construction the “Event Tree” is outlined in the literature [5], [9]. They also display how AS will react on initial event, will the safety functions be fulfilled during the process that is the condition of safety maintenance. The structure of the “Event Tree” includes one main event (e.g. specific situation during the flight) which relates to the set of following relevant events (mistake, failure, influence of unfavourable events) that form the chain of causes (scenarios). The combination of failure, mistakes of individuals and uncalculated external influences factors are identified analysing the “Event Tree” that lead to the main event.

The conditional probability is displayed between the events at the nods of the tree for the interconnection between them. The occurrence of each scenario’s development in the situation is calculated by multiplying the occurrence of main event by the conditional probability of the end event. The method is used to analyse possible reasons of happening specific situation during the flight and to calculate the frequency (probability of event’s occurrence) [8].

To describe the causations of “tree”, an information from the different sources are analysed:

- Official reports about the investigation of aviation events;
- Manuals, instructions and regulations of the air companies that are related to the fulfilment and maintenance of the safety;
- Technical manuals associated with construction and systems of the airplanes and other equipment;
- Analytical and statistical researches from different safety organization.

Model of predicted probabilities of unfavourable events is designed on the base of the “tree”. Decryption of the records of flight data; aircraft reliability data; private, national and world statistic about the aviation’s unfavourable events; forecast information; information about the protection of the objects from terroristic activities are used as an initial date. The use of “tree” allows evaluate probability of specific type of aviation event during the conditions and find a potential threat that can influence this event.

IV. Prediction of Risks in Air Transportation Based on the "Event Tree"

A. Risk Assessment of Aviation Accident Under the Influence of the Adverse Factors During Flight

To calculate the probability of safe flight, consider the "Event Tree" as a sequence of aircraft transitions in flight from one state to another (Fig. 1).

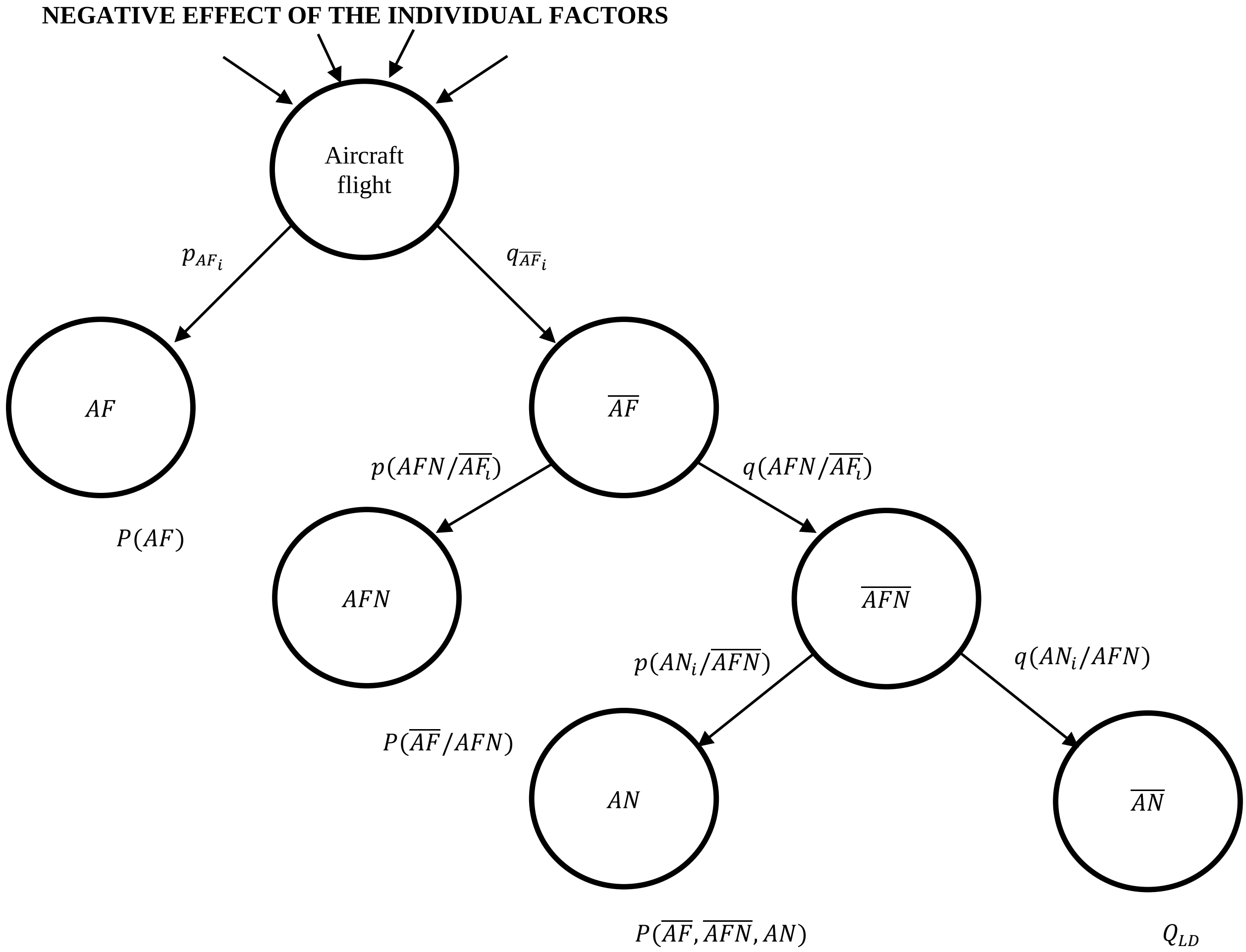

Fig. 1. Diagram of accident development process.

Designation of appropriate "crew – aircraft" system state:

- AF and $\overline{AF}$ – Crash factor not manifested/manifested;
- AFN and $\overline{AFN}$ – Crash factor corrected/not corrected;
- AN and $\overline{AN}$ – Flight favorable ending/aviation accident.

The possibilities of transitions from one state to another are denoted by arrows (arcs) [9]. The probabilities of transition are marked on arrows. When determining the probability of successful completion of flight $P_{LD}(t)$ should consider different options for possible transitions [10].

1. No crash factor in flight (event AF). In this case the probability $P_{LD}(t)$ will be appropriate for the probability of an accident

$$P_{AF} = p_{AF_i} \tag{2}$$

2. In a flight the system may result in an emergency factor AF with a probability of $q_{\overline{AF_i}}$. Its appearance means only an aviation accident possibility, not inevitability. At the beginning of the event, the aircraft parameters are at some rate different from those of the committed. When it is found from information sources, the pilot will try to prevent the consequences of the accident factor and, above all, seek to eliminate the parameter X_i, which is bounded by the safety conditions of the flight, outside of the permissible limits $(\alpha \leq \alpha_{perm}, n_y \leq n_{y\,perm}, M \leq M_{perm})$. In general, the pilot can prevent the consequences of an accident factor $\overline{AF}$ or not prevent.

Let's presume probability of this event by $p(AFN/\overline{AF}_i)$ and $q(\overline{AFN}/\overline{AF}_i)$, respectively. In the case of a favorable ending of the flight, in the event of the pilot's intervention and the consequences of the factor:

$$P_{LD}\{\overline{AF}_i/AFN\} = q_{\overline{AF}} \times p(AFN/\overline{AF}_i) \quad (3)$$

3. If, despite the intervention of the pilot, the relevant parameters have gone beyond the permitted limits, this does not necessarily end with an aviation accident. Suppose that the effect of an incident is to exceed the permissible angle of attack and the aircraft starts to settle down. In this case, the pilot, with the right actions, can prevent the aircraft from going down and prevent an accident from the aircraft. The probability of an accident elimination following the departure of the determination parameter outside the permitted limits, using $p(AN_i/\overline{AFN})$.

A probability of favourable ending of the flight after an accident and departure of the determinants outside the limits is:

$$P_{LD}\{\overline{AF}_i, \overline{AFN}, AN_i\} = q_{\overline{AF}_i} \times q(\overline{AFN}/\overline{AF}_i) \times p(\overline{AN}_i/\overline{AFN}) \quad (4)$$

The probability that the flight will end with an aviation accident (i) due to the accident, the probability of multiplication theory can be expressed as:

$$P_{LD}\{\overline{AF}_i, \overline{AFN}, \overline{AN}_i\} = Q_{LD}(t) = q_{\overline{AF}_i} \times q(\overline{AFN}/\overline{AF}_i) \times q(\overline{AN}_i/\overline{AFN}) \quad (5)$$

So, the probability of a flight's favourable ending is:

$$P_{LD}(t) = 1 - Q_{LD}(t) = 1 - q_{\overline{AF}_i} \times q\left(\frac{\overline{AFN}}{\overline{AF}_i}\right) \times q\left(\frac{\overline{AN}_i}{\overline{AFN}}\right) = 1 - (1 - p_{AF_i}) \times \{1 - (\overline{AFN}/\overline{AF}_i)\} \times \{1 - (\overline{AN}_i/\overline{AFN})\} \quad (6)$$

In most cases, the notional probability of prevention of an accident in the aviation situation is $p(AN_i/\overline{AFN})$. Than the probability of a flight's favourable ending is:

$$P_{LD}(t) = p_{AF_i} + (1 - p_{AF_i}) \times p(AFN/\overline{AF}_i) \quad (7)$$

Thus, the probability of successful completion of the flight on the i-th risk factor depends on the probability of its non-appearance in flight and the conditional probability of the pilot parry of the output defining parameters beyond the permissible limits. The risk level of an aviation accident in this case will be:

$$Q_{LD}(t) = 1 - P_{LD}(t) \quad (8)$$

B. Prediction of the Probability of a Ground Accident During Maintenance.

A ground accident is an accident that occurred before or after the flight [11]. It relates to the movement of special vehicles on the territory of the airfield to perform a certain task or unauthorized travel, which also has a frequent place. To carry out a priori quantitative assessment of the probability of a ground transport accident, statistical data on accidents in similar transport processes and modelling the process of their appearance by means of causal diagrams in the form of "Event Tree".

C. Assessment of the Probability of Ground Aviation Accident Q

Let's consider the possibility of a ground aviation accident of a special vehicle performing a trip to perform maintenance of the aircraft preparing for the flight. Along the route there is a crossing of the taxiways of airplanes with traffic lights. The car moves on the known route. All potentially dangerous areas and intersections are known in advance. Monitoring of their condition for a certain period of time allowed to get probabilistic indicators of their possible states and this information is used to inform drivers through dispatching services [12].

Imagine a possible incident model in the form of an “Event Tree” (Fig. 2). Possible states of route sections, actions of the driver, the information received by him and their quantitative values in the form of probabilistic values for a certain period (year) are available in an automated system and they can be received in a Table I.

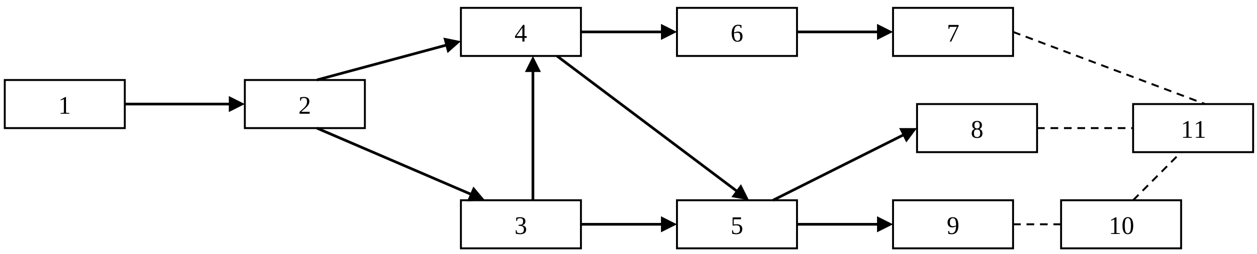

Fig. 2. “Event Tree” of a ground aviation accident.

Here the rectangles and arrows (arcs) characterize the events and their possible sequence in the process of vehicle movement.

TABLE I

TRANSPORT ACCIDENT PARAMETERS

ARC number	**Semantic value of variable graph**	**Symbol**	**Size**
1–2	The vehicle came out with the task	P1	1/year
2–3	Section is closed	P2	0.1
2–4	Section is free	$\underline{P}2$	0.9
3–4	The road is free, traffic light works	$\underline{P}3$	0.9
3–5	Traffic lights don’t work	P3	0.1
4–5	The driver did not notice the idle traffic lights	P4	$1 \cdot 10^{-4}$
4–6	Driver is warned of broken traffic lights	$\underline{P}4$	0.999
5–8	The driver did not react to the warning	P5	0.1
5–9	The driver reacted to the warning	$\underline{P}5$	0.9
6–7	Technical capabilities are not enough to prevent collision	P6	$1 \cdot 10^{-8}$
9–10; 7, 8, 10–11	Fictitious link (logical condition)		1.0

The analysis of the structure of this "Event Tree" shows that there are no closed loops in it, and nodes 4 and 5 can be implemented at a specific time only by one of the incoming arcs. Therefore, for the occurrence of a traffic accident (collision), it is enough to reach section 11 on any of the following branches:

1) 2+3+5+9;
2) 2+3+4+5+9;
3) 2+3+5+8;
4) 2+3+4+5+8;
5) 2+4+6+7;
6) 2+3+4+6+7;
7) 2+4+5+9;
8) 2+4+5+8.

Then the total probability of a ground aviation accident will be equal to the sum of probabilities of all eight branches of our "Event Tree".

$$Q = \mathrm{P2P3}\underline{\mathrm{P5}} + \mathrm{P2}\underline{\mathrm{P3}}\mathrm{P4}\underline{\mathrm{P5}} + \mathrm{P2P3P5} + \mathrm{P2}\underline{\mathrm{P3}}\mathrm{P4P5} + \underline{\mathrm{P2P4}}\mathrm{P6} + \mathrm{P2}\underline{\mathrm{P3P4}}\mathrm{P6} + \underline{\mathrm{P2}}\mathrm{P4}\underline{\mathrm{P5}} + \underline{\mathrm{P2}}\mathrm{P4P5} = 0.001 \quad (9)$$

$Q = 1 \times 10^{-3}$ *1/year,* i.e. a thousand trips have one collision with a moving aircraft. This is the probability of one ground aviation accident for one vehicle when driving on the airfield on the known route.

D. Estimating the Probability Q of a Terrorist Act Being Committed

Recent trends have shown that the conduct of terrorist acts is becoming more and more adjusted and sophisticated [13]. The attempts to achieve the maximum number of human casualties, property damage and destabilization of social and political life in the country are characteristic features of the aspirations of the perpetrators and organizers of the attacks. It should be noted that committing a terrorist act is not an end in itself, but a means of achieving, as a rule, certain political objectives. Suppose that the transported dangerous cargo in the airport area may be prone to sabotage with the purpose of its capture and subsequent blackmail [14]. The possibility of this action depends on the characteristics of the route, the degree of its protection technical (locks, fences, checkpoints) and organizational measures (the presence of security, the ability to call reinforcements), etc. Given these circumstances of the success of sabotage – the probability that terrorists overcome the resistance of protection and reinforcement, neutralize the technical means of cargo protection, can be obtained "Event Tree" of the sabotage results, presented in the Fig. 3.

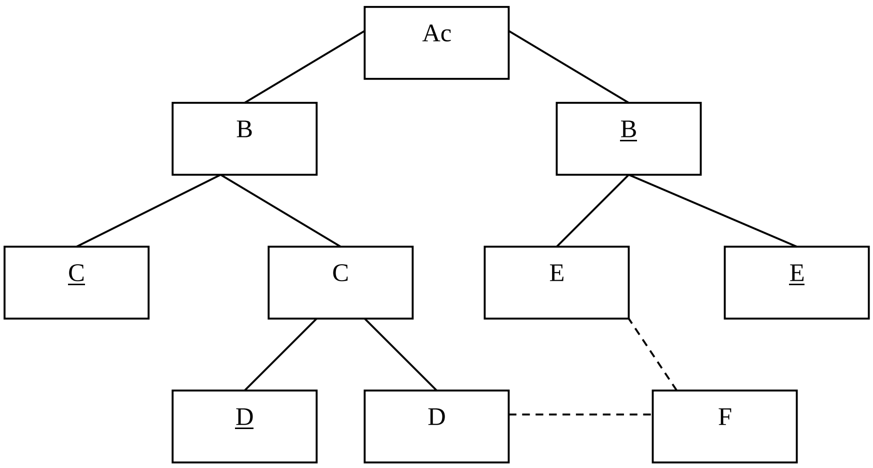

Fig. 3. Result of sabotage “tree”.

- Ac – Attack;
- B – Destruction of the carrier;
- $\underline{B}$ – Carrier calls for reinforcements (employees of security structures);
- C – Overcoming technical means of protection;
- $\underline{C}$ – Failure to overcome technical means of protection;
- D – Destruction of the arrived reinforcements;
- $\underline{D}$ – The seizure of terrorists;
- E – Liquidation of the arrived reinforcements and the driver with the subsequent overcoming of technical means of protection;
- $\underline{E}$ – The seizure of terrorists;
- F – Mastering the cargo.

This model illustrates three possible ways to successfully complete an attack, including events: A+B+C, A+B+C+D and A+$\underline{B}$+E. Their sequence accordingly designates:

- The attackers destroy the carrier and penetrate through the technical means of protection before the arrival of reinforcements;
- After the carrier’s liquidation and the commencement of hardware hacking,

reinforcements arrive, but they are destroyed by terrorists, and then they complete access to the dangerous cargo;

- To help the carrier immediately arrives reinforcements, but both are liquidated by terrorists as well as technical means of protection of cargo in the future.

It is easy to see that under the conditions specified above, these scenarios are exhaustive and mutually exclusive [15]. Assuming the possibility of only a single attack on the entire route of transportation of cargo consisting of M intervals with degrees of threat Sk and the duration of the movement of Tk, the expression for the probability of successful completion of sabotage takes the following View:

$$Q = \Sigma P(C/Ac) + \mathrm{P}(D/Ac) + \mathrm{P}(E/Ac) = \Sigma SkTk\mathrm{P}(F/Ac)/\Sigma SkTk \qquad (10)$$

Where $P(F/Ac)$ – the probability of successful completion of sabotage on a specific section of the route.

The probability of terrorists destroying the carrier $P(C/Ac)$ is determined by the semi-Markov model [16], as the final chance of retaining at least one of the terrorists. This model considers the number of available, their training, equipment, initial position and tactics of combat. Similarly, there are probabilities $P(D/Ac)$, $P(E/Ac)$, $P(F/Ac)$.

V. CONCLUSION

1. In assessing the risks of adverse situations in aviation transport distinguish risks related to safety and security of aviation. This means that we can make full use of the same methods for improving the efficiency of the air transport Safety system by identifying analysis, assessment and mitigation measures to the acceptable level and their Control. At the same time, the risk is considered as a risk of social and economic damage to the person, enterprise, society.
2. Airlines use automated forecasting and accident prevention systems, which use "event trees" to determine the safety score, which are graphic models that display Development of the adverse event.
3. In the article in accordance with the proposed methodology, three topical tasks related to the safety of air transport were considered.
4. The ability to predict the risk of socio - economic damage makes real management of the safety of aviation, the purpose of which is to minimize the total cost of objectively existing prerequisites accidents on air transport. Risk prediction with the help of unified methodology will improve mutual understanding of liability insurance, economic mechanism of aviation safety management, etc.

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