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КАФЕДРА АЕРОНАВІГАЦІЙНИХ СИСТЕМ

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри

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ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА

ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ

«ОБСЛУГОВУВАННЯ ПОВІТРЯНОГО РУХУ»

Тема: «Метод оптимізації процесу управління факторами ризику авіаційних подій на основі критерію мінімальних загальних витрат»

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The specialty: *272 "Aviation Transport"*

Educational Professional Program: *Systems of Air Navigation Service*

APPROVED BY

Head of the Department

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"____"_____________2020

Master's Thesis Assignment

Student`s name: Yenotova Mariia Maksymivna

1. The thesis theme: **" Method of optimization of the process of managing risk factors of aviation events based on the criterion of minimum total costs"**

   Approved by the Rector's order *of "29" September 2020 № 1815/cm.*

2. The thesis should be performed from: *5.10.2020 to 13.12.2020*

3. Initial data: *flight safety management system in airlines, Poisson's law, data about total costs of aviation events.*

4. The content of the explanatory note (the list of problems to be considered): the process of managing risk factors of aviation events, a mathematical model of the total costs, the level of effectiveness of measures to reduce the risks of aviation events, develop the concept of software for calculating the optimal level of efficiency of measures to reduce the risks of aviation events.

5. The list of mandatory graphic materials: *<u>26 figures, 7 tables, 49 formulas. Power Point should be used to provide graphic support and presentation.</u>*

6. Calendar Schedule of Performing the Master's thesis.

№	Task	Deadline	Mark of performance
1	Preparing and writing a section 1 "Analysis of theory and practice of risk management of aviation incidents in the safety management systems of airlines"	01.09.20 – 11.09.20	Performed
2	Preparing and writing a section 2 Development of a mathematical model of total costs for providing flight safety and elimination of the consequences of aircraft incidents in the safety management system of airlines	11.09.20-12.09.20	Performed
3	Preparing and writing a section 3 Development of the software for calculation of the optimum probability of preventing aviation incidents	13.09.20 – 25.09.20	Performed
4	Preparing and writing a section 4 Optimizing the process of managing the risks of serious incidents in the operation of civil aviation aircraft using the software calculations of the optimum aviation events prevention probability	26.09.20– 26.10.20	Performed
5	Preparing and writing a section 5 "Preparation of presentation and report"	27.10.20 –	Performed

		04.11.20	

8. Date of issue: «___»_____________ 2020.

Supervisor of master’s thesis _________________ ________________

Excepted the task _________________ ________________

ABSTRACT

The master thesis assignment to diploma work “Method of optimization of the process of managing risk factors of aviation events based on the criterion of minimum total costs” contains 26 illustrative figures, graphs, 49 formulas and 7 tables.

The object of research in the work is the airline flight safety management system.

The subject of the research is a method of increasing the efficiency of the airline's flight safety management system.

Purpose of the investigation is to develop a method for optimizing the process of managing the risk factors of aviation events based on the criterion of minimum total costs, which makes it possible to increase the efficiency of the flight safety management system in terms of making decisions on the level of improving flight safety.

Methods of investigation: in the course of the research, the methods of mathematical analysis, the theory of probability and mathematical statistics, the theory of mathematical modeling, as well as programming algorithms for computer programs were used.

In this diploma work are investigated an assessment of the risks of aviation events and the amount of costs for measures that reduce the risks of aviation events, taking into account the likelihood of preventing aviation events, the value of the probability of preventing aviation events was obtained, the value of the probability of preventing aviation events can be obtained, the assessment of the total costs in the flight safety management system, aimed at eliminating possible damage from aviation events and ensuring flight safety, taking into account the probability of preventing aviation events, has been carried out.

АРКУШ ЗАУВАЖЕНЬ

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LIST OF SYMBOLS

SMS – Safety Management System

ICAO –International Civil Aviation Organization

SSMSP – State Safety Management System Program

SARPs – Standards and Recommended Practices

SSPs – State Safety Programs

ARMS – Automatically Risks Management System

FCC – Flights Control Center

SMM – Safety Management Manual

SQL – Structured Query Language

INTRODUCTION

In aviation, flight safety is a fundamental condition that determines its purpose, activity and development.

In order to manage and control the level of flight safety, airlines are developing a safety management system (SMS). The development of methodological materials for SMS is a topical issue that conferences and seminars are devoted to annually.

The safety of air transport operation is influenced by many negative factors, the impact of which can have various negative consequences. It is impossible to achieve absolute safety, while the costs of ensuring flight safety tend to infinity, at the same time, a lack of investment in ensuring flight safety can lead to disaster. In this regard, a mechanism is needed to determine the priority risks and the most effective measures to reduce their level in such a way that a balanced distribution of investments for ensuring flight safety and ensuring the production objectives of airlines is ensured.

The object of research in the work is the airline flight safety management system.

The subject of the research is a method of increasing the efficiency of the airline's flight safety management system.

Purpose of the work: To develop a method for optimizing the process of managing the risk factors of aviation events based on the criterion of minimum total costs, which makes it possible to increase the efficiency of the flight safety management system in terms of making decisions on the level of improving flight safety.

Tasks:

1. To analyze the process of managing risk factors of aviation events within the framework of flight safety management systems of the airlines.

2. Develop a mathematical model of the total costs of implementing measures to reduce the risks of aviation events and eliminate the expected damage from aviation events.

3. Determine the level of effectiveness of measures to reduce the risks of aviation events, the achievement of which ensures the minimum total costs of reducing the risks of aviation events and eliminating potential damage from aviation events, with the greatest reduction in risks.

4. To develop the concept of software for calculating the optimal level of efficiency of measures to reduce the risks of aviation events, taking into account the criterion of minimum total costs.

Research methods

In the course of the research, the methods of mathematical analysis, the theory of probability and mathematical statistics, the theory of mathematical modeling, as well as programming algorithms for computer programs were used.

The novelty of the work lies in the fact that in it:

1. An assessment of the risks of aviation events and the amount of costs for measures that reduce the risks of aviation events, taking into account the likelihood of preventing aviation events, was carried out.

2. For the first time, evaluation of the probability of preventing aviation events is proposed, which will ensure the reduction of the risks of aviation events at minimum total costs.

3. Evaluation of the effectiveness of measures to reduce the risks of aviation events using the probability of preventing aviation events is proposed.

4. The assessment of the total costs in the flight safety management system, aimed at eliminating possible damage from aviation events and ensuring flight safety, taking into account the probability of preventing aviation events, can been carried out.

Theoretical significance:

1. For the first time, a method is proposed for calculating the risks of aviation events and the amount of investments required to reduce them, taking into account the probability of preventing aviation events in air transport.

2. A new approach to improving the efficiency of the flight safety management system in terms of preparing solutions to reduce the risks of aviation events during the operation of aircraft in the activities of the airline

3. The dependence of the probability of preventing aviation events during the operation of aircraft on the costs of implementing measures to improve flight safety was revealed.

Practical significance:

1. The method of optimization of the process of managing risk factors of aviation events based on the criterion of minimum total costs can be introduced into the activities of the regional state government institutions, development of the aviation cluster of all of the Ukrainian regions for the preparation of proposals for optimizing financial costs while reducing the risks of aviation events in the flight safety management system of airlines.

2. The method of optimization of the process of managing the risk factors of aviation events will make it possible to determine the level of increase in flight safety at minimum total costs in the flight safety management system.

3. The developed in future software for calculating the optimal level of the probability of preventing aviation events will make it possible to form a set of

measures that minimize the risks of aviation events with minimum total costs during the operation of air transport.

4. Proposals for the further development of the method for calculating the optimal level of probability of preventing aviation events are presented.

CHAPTER 1. ANALYSIS OF THEORY AND PRACTICE OF RISK MANAGEMENT OF AVIATION INCIDENTS IN THE SAFETY MANAGEMENT SYSTEMS OF AIRLINES

Ensuring flight safety is a complex and important task that requires financial support, timely and rational implementation of a set of measures, in most cases systemic, in the context of the functioning of each element of the aviation transport system.

There are always risks of accidents and incidents in the activities of airlines. The consequences of risks can be catastrophic. In this regard, there is a need to manage risk factors. The level of flight safety directly depends on the competitiveness of the airline. The largest airlines tend to have the highest safety scores.

State Aviation Service of Ukraine by order of 26.07.2012. No. 528 approved the Guidelines for the implementation of flight safety management systems, with the aim of providing aviation entities with recommendations, clarifications and methodological assistance regarding the planning and implementation of flight safety management systems.

The development of better SMS methods and rules for airlines is a pressing issue.

1.1. Implementation and operation of a safety management system in airlines

1.1.1. Documents regulating the implementation and operation of flight safety management systems

In the documents that regulate the management of the state of safety of civil aviation flights, the stages of identifying and analyzing information on negative factors that can lead to a decrease in the level of flight safety, the development of appropriate preventive measures are provided as the main activity to prevent aviation events.

The Convention on International Civil Aviation (Chicago Convention) is the main document in the field of ensuring the safety of civil aviation.

According to Appendix 6 to the Chicago Convention, states must adopt states safety programs (SSPs).

To clarify ICAO safety management standards and recommended practices, including the development and implementation of SMS and SSP, the Safety Management Manual (SMM) has been issued (currently the third edition of Doc. 9859 AN / 474 is in force).

Annex 19 to the Chicago Convention "Safety Management" concentrates the provisions of six Annexes related to flight safety ("Licensing of Aviation Personnel", "Aircraft Operation", "Airworthiness of Aircraft", "Air Traffic Services", "Aircraft Accident Investigation and incidents", "Aerodromes" (volume I)), including material on SSP, SMS.

As part of the fulfillment of the obligations of Ukraine arising from the Convention on International Civil Aviation, as well as with the aim of introducing a safety management system in civil aviation, capable of ensuring "a steady reduction in the number of aviation accidents and human casualties with a simultaneous increase in the pace of modernization of the industry in all areas of activity" [30], State Aviation Service of Ukraine by order of 26.07.2012. No. 528 approved the Guidelines for the implementation of flight safety management systems, with the aim of providing aviation entities with recommendations, clarifications and methodological assistance regarding the planning and implementation of flight safety management systems.

In accordance with the State Program, scientific support for flight safety is "a prerequisite for choosing promising areas and increasing the efficiency of activities to ensure the safety of civil aviation flights".

The action plan of the State Program provides for the development of methodological guidelines and recommendations in the field of flight safety with scientific substantiation of ways to prevent aviation accidents.

The SMS should include identification, assessment of negative factors for flight safety, development of preventive measures, monitoring and assessment of the level of flight safety, improving the level of flight safety.

In the introduction of the safety requirements for the implementation of SMS can be perceived by operators critically in connection with the fact that:

- if there are requirements, there are no rules and methods for their implementation. The problem of the lack of methodological and scientific support for the implementation of SMS in airlines should also be discussed. This work is aimed at a partial solution of this issue;

- the presence of different points of view on fundamental issues, including on flight safety indicators (FSI), set and acceptable levels;

- lack of unambiguity in the concepts used.

The ICAO SMM, which contains a number of conceptual frameworks and basic requirements for ensuring the safety of civil aviation for ICAO member states, should not have any tools. Each state, on the basis of this document and its provisions, develops an SSMSP and, on its basis, normative acts reflecting the detailed methods and rules for developing an SMS, taking into account the specifics of the state and the corresponding regulatory framework.

A number of documents in force in the Ukraine contain general concepts and methods for preventing aviation accidents; some of them, in terms of impact on risk, provide for cost savings and minimization of possible damage.

The provision on the optimal balance between safety and the requirements that a product, process or service must satisfy, and profitability, is set out in the Air Code of Ukraine, Section III - Basic mechanisms for aviation safety management, Article 10. Ensuring aviation security.

The process of taking control actions in relation to risk is not disclosed in the documents.

All airlines should develop SMS based on their characteristics and availability of resources [99], with subsequent coordination with the regulatory body in the field of civil aviation.

When introducing SMS, airlines faced such problems as the presence of contradictions in regulatory documents on technogenic safety in the Ukraine as a whole, the presence of inaccuracies in the translation of ICAO documents into Ukrainian [108].

The following are the key issues in ensuring the implementation of SMS in airlines:

- legal acts defining the state policy regarding the creation of an SMS were not issued;

- an acceptable level of flight safety has not been established;

- the SMS implementation procedure is not regulated;

- no direct responsibility for the flight safety of the senior management of the enterprise has been introduced.

Article 31 of the Air Code of Ukraine (State supervision of aviation safety) further provides that a specially authorized central executive body carries out state supervision of aviation safety. At the same time, the interaction of the executive authorities of Ukraine regarding the supervision of the safety of aircraft flights is carried out in accordance with the procedure established by the Cabinet of Ministers of Ukraine.

There is a possibility that the existing SMS of airlines will need to be adjusted to a greater or lesser extent and brought in line with the new procedures.

It must be noted that the basis for ensuring flight safety is "the creation of effective safety management systems for aviation activities, as well as flight safety management systems". The air users should note "the need for the development and implementation of national aviation safety management standards, including flight safety management system standards".

Thus, there is no unified standard for the development and implementation of SMS, and on the territory of the Ukraine, at present, the state policy in this area is just beginning to form.

1.1.2. Safety Management System Conceptual Frameworks

The minimum requirements that should include an SMS for ICAO SMM, Annex 6 to the Chicago Convention, is the content of four components and twelve elements for the allocation of responsibilities between officials and the implementation of activities in the field of flight safety, identification, analysis, assessment of the risks of aviation events, taking measures to reduce the level of risks of events, conduct training of aviation personnel and inform in the field of flight safety.

Safety risk management is one of the main elements of an SMS.

Risk reduction is possible in various ways (for example, equipment replacement, staff training, etc.).

To implement the components effectively, methodologies need to be developed for each SMS element. The operating airlines have already developed systems and have their own developments in this area. The decision-making to correct the level of risk of aviation events is based on the expert method, and this stage is a difficult and “weak link” in SMS (also abroad).

It turned out that the component "risk factor management" of the SMS contains from 30 to 50 percent of gaps within the time and the practice.

It is known that it is impossible to ensure zero risk in functioning systems.

Currently, the concept of absolute safety has been rejected and the concept of acceptable (acceptable) risk is used, the essence of which is to strive to ensure such a level of risk that is acceptable in a given period of time, or the lowest practicable level.

Achieving the lowest practicable level is determined by the financial resources of the organization. Appropriate resource allocation is one of the most important organizational processes for airlines. Lack of funding for measures to ensure flight safety can negatively affect flight safety, while excess funding will negatively affect the financial condition of the company ("Protection and Production dilemma").

When an accident occurs, in addition to the insured costs (covered by insurance premiums paid to insurance airlines) that can be reimbursed, there are also uninsured costs that cannot be reimbursed and, as a rule, are twice or three times the insured costs [104]:

- insurance deductions; lost time and overtime;
- the cost of the investigation;
- the cost of hiring and training replacement;
- loss of productivity of injured personnel;
- the cost of restoring order;
- lost time of equipment use;
- the cost of renting or leasing replacement equipment;
- increased operating costs for the remaining equipment;

- loss of spare parts or specialized equipment;
- fines and summons to court;
- payment for legal services provided in connection with the incident;
- increased insurance premiums;
- payments for obligations in excess of the insurance amounts;
- decrease in business volume and damage to reputation;
- remediation costs.

Thus, in the management of flight safety, it is important to carry out a balanced distribution of resources between "protection" and "production", as well as to define in the safety space "financial and safety boundaries - boundaries, the achievement of which indicates that a situation of unbalanced distribution of resources is created" (figure 1.1).

C_{min}- minimum total costs;

R_{opt} - the level of risk of an aviation event corresponding to the minimum total cost.

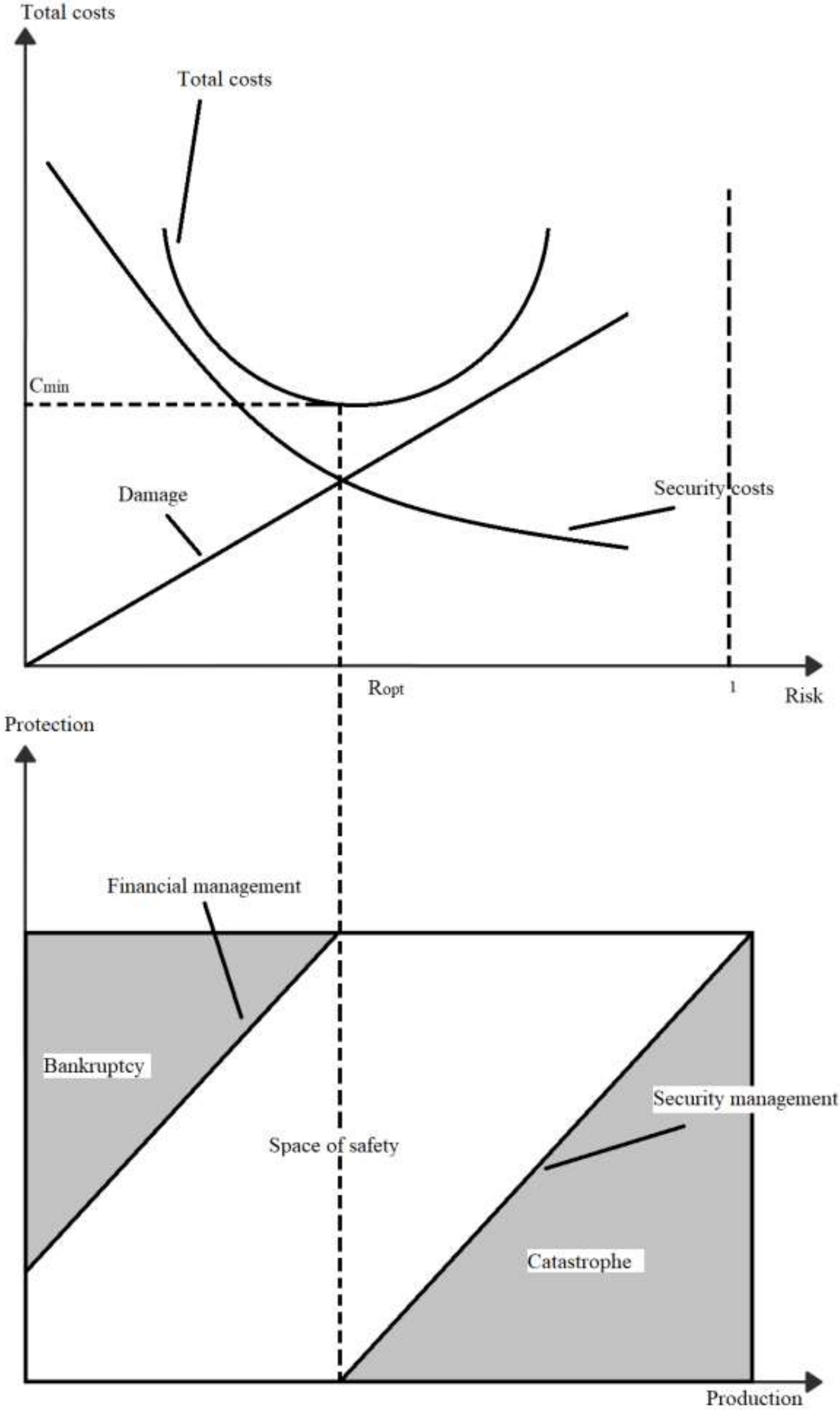

Total costs
Total costs
Cmin
Damage
Security costs
Ropt
1
Risk
Protection
Financial management
Bankruptcy
Space of safety
Security management
Catastrophe
Production

Figure 1.1 - Safety space boundaries in the safety management system

It is impossible and economically inexpedient to eliminate all possible negative factors affecting flight safety immediately.

Taking this into account, making a decision to reduce the risks of aviation events will be much more effective if from all the considered measures to improve flight safety, first of all, select those that will ensure a balance between the costs of ensuring flight safety and organizing production. In order to make such a sample, it is necessary to develop a mathematical model of total costs with an optimization parameter - the effectiveness of measures to increase the level of flight safety, then find the optimal value of the effectiveness of measures based on the criterion of minimum total costs.

The mathematical model of total costs will be the basis of the method for optimizing the process of managing risk factors of aviation events based on the criterion of minimum total costs in the airline's flight safety management system. Such a method would be a solution to the dilemma that arises in the "security space".

Until now, the proposed approach to improving flight safety based on the criterion of minimum total costs has not been considered and is of certain interest in the field of improving the efficiency of the existing SMS of airlines.

1.2. Methods for managing risk factors of aviation events in airline flight safety management systems

The "propaganda of achievements in the field of flight safety of the country's civil aviation leaders" is recommended as one of the priority directions for improving flight safety in the world.

As part of the study of the SMS used, the experience of the next airlines was studied: Ukraine International Airlines, Wind Rose Aviation Company, SkyUp Airlines LCC, Azur Air Ukraine Airlines LLC, Motor Sich Airlines, Wizz Air Hungary Ltd.

Ukraine International Airlines is the leader in the number of passengers carried, it operates domestic and international passenger flights and cargo services to Europe, the Middle East, the United States, Canada, and Asia. Ukraine International Airlines fleet has 34 aircrafts total in service, 18 of them - are Boeing 737-800.

To date, the structural divisions of UIA have carried out the following work to implement SMS:

- a program for assessing risks in relation to flight safety has been developed;

- identified the main categories and classes of aviation events;

- developed a unified risk matrix for all production structural divisions and BP inspection;

- the tasks of structural divisions in the process of identifying hazards and developing recommendations for reducing the risks of aviation events were determined;

- methods for managing risk factors have been determined;

- developed an organizational structure for the collection and processing of information about aviation events and related risks.

Activities to improve the level of flight safety at JSC UIA include the following tasks:

- reduction in the number of damages to aircraft;

- increasing the reliability of the aircraft fleet;

- elimination of personnel errors affecting the safety level;

- introduction into operation of new types of aircraft (AC).

After ranking the identified risks, the airline determines the risk factor management strategy separately for each type of risk with priority being given. Priority in the order of risk elimination is established based on the following criteria:

- the share of the corresponding costs in the structure of the airline's expenses, as well as indirect costs associated with the presence of a particular risk;
- the highest probability of occurrence of events (based on expert judgment);
- the possibility of influencing the risk without additional funding;
- the ability to analyze risks and impact on risk at an early stage of new major airline projects;
- continuation of already started projects.

To manage the level of flight safety, a predictive risk management strategy is used, which consists in identifying potential events that have not previously occurred, having an internal or external source and negatively affecting flight safety, as well as developing measures to reduce the risks of identified events (Figure 1.4).

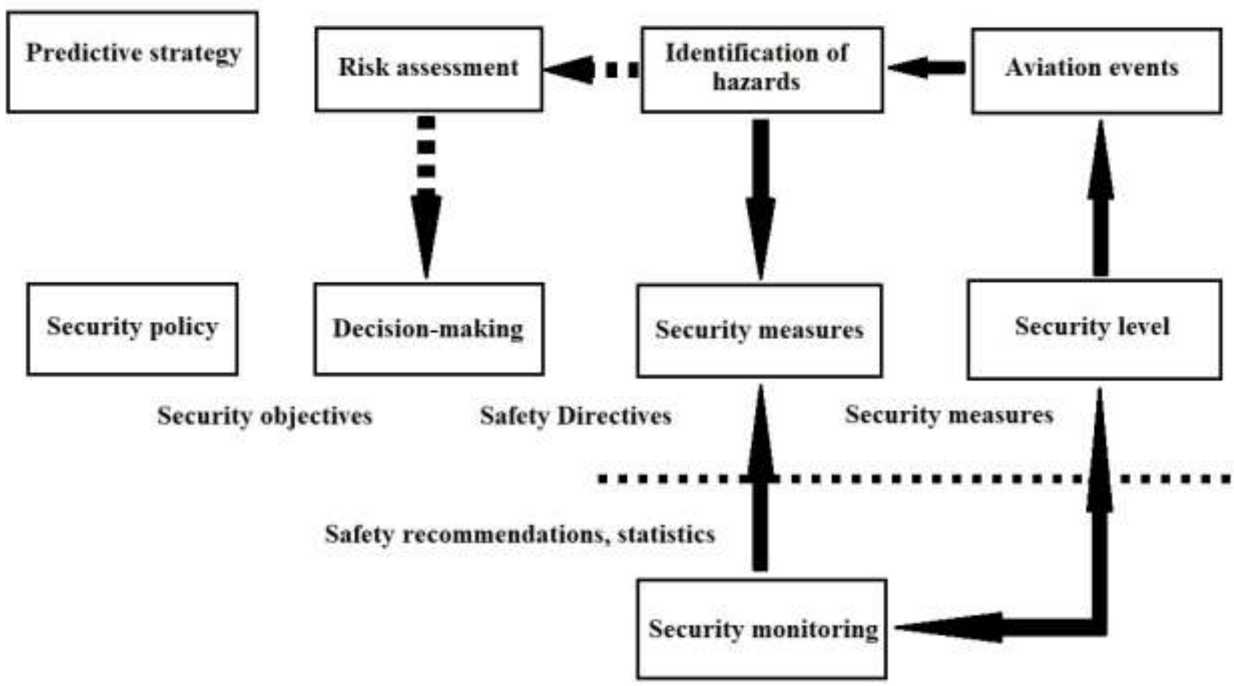


Figure 1.2 - Risk factor management strategy used at UIA OJSC

According to the developed methods in the field of operational risk management, UIA specialists identified four main ways of responding to risks:

- risk aversion - termination of risk-related activities;
- risk reduction - actions to reduce the likelihood of risk;
- risk redistribution - reducing the likelihood of risk by insuring or transferring any type of activity to a third party;
- risk acceptance - no action is taken to reduce the likelihood of risk.

Reducing the severity of the consequences or the likelihood of risk will reduce the associated risk, while both variables can be reduced, or either variable individually, resulting in a reduction in risk.

The process of managing risk factors is shown in Figure 1.5.

In this regard, the following options for risk reduction arise:

- technical measures;
- control measures;
- personnel decisions, economic impact on personnel;
- organizational and production solutions.

As a rule, the analysis of production activities shows that it is impossible and economically unprofitable to eliminate all existing hazards, and, in this case, the rule for choosing priority areas comes into force.

Windrose airlines, legally Wind Rose Aviation Company, is a Ukrainian charter airline based at Boryspil International Airport. Founded on 28 October 2003, the airline's headquarters is in Kyiv; it operates charter flights to destinations in Europe, Turkey, Israel and Egypt.

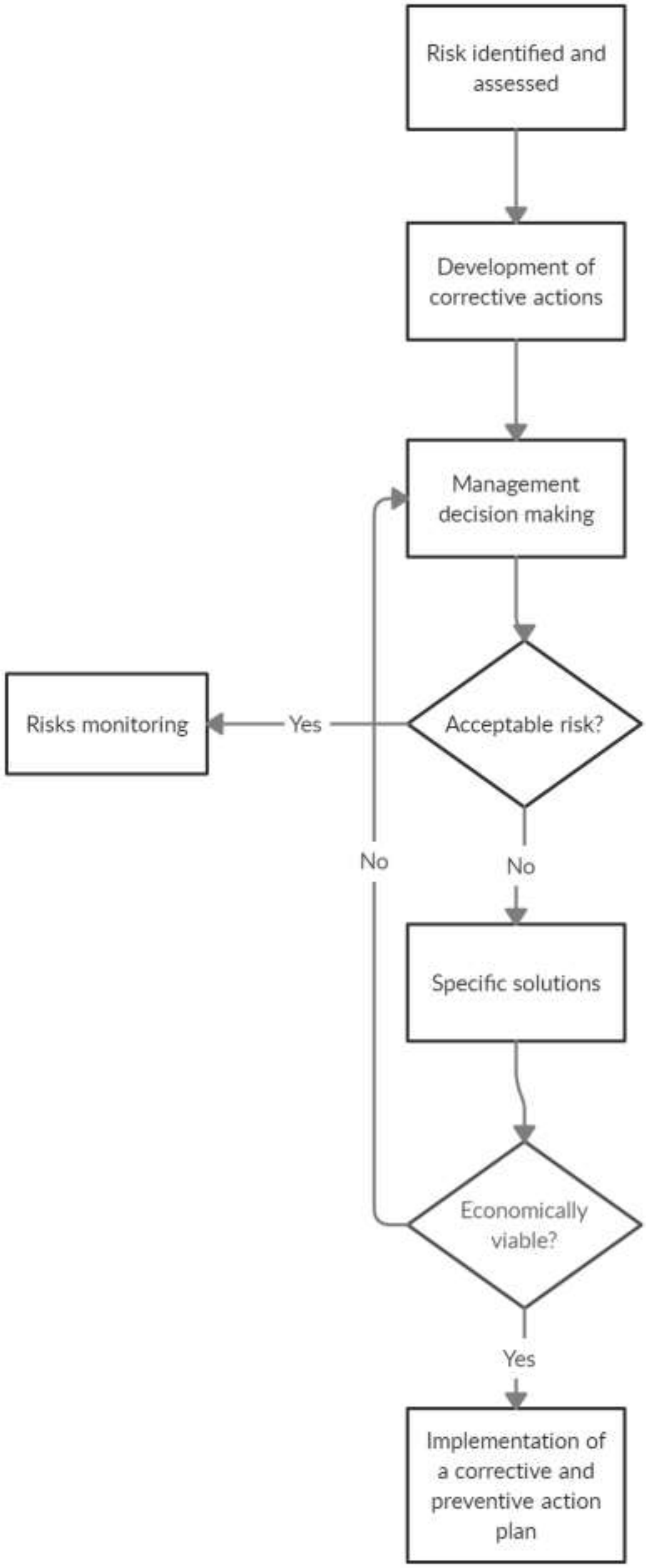

Risk identified and assessed
Development of corrective actions
Management decision making
Acceptable risk?
Yes
Risks monitoring
No
No
Specific solutions
Economically viable?
Yes
Implementation of a corrective and preventive action plan

Figure 1.3 - Algorithm for influencing risks in the flight safety management system of JSC "UIA"

At Windrose Airlines an SMS includes three stages:

- the first step is to identify hazards. Hazards can be identified both on the basis of an analysis of the aviation events that have taken place, and through an assessment of potentially dangerous sources of danger.

- the second stage is risk assessment using the risk assessment matrix (Figure 1.6). When performing this work, the airline specialists proceeded from the concept of risk as a measure of the probability of a dangerous situation and the severity of its consequences. Depending on which area the risk assessment falls into for each of the criteria (blue, yellow or red), the risk is characterized as acceptable, acceptable and unacceptable.

Potential consequences				Probability of occurrence				
Assessment	Trauma	Environment, property	Reputation	A(1) Theoretically possible	B(2) Occurred in the industry	C(3) Occurred in the industry more than 3 times	D(4) Occurred in the company	E(5) Occurred in the company more than 2 times
1	Minor (no hospitalization)	Minor	Minor (no damage)					

4	3	2
Catastrophic (fatal)	Serious (severe injuries)	Substantial (no severe injuries)
Catastrophic	Serious	Substantial
Catastrophic (international	Serious (damage at federal level)	Substantial (damage at industry level)

Figure 1.4 - Risk Assessment Matrix

- the third stage is the development of measures to reduce the risk to the "lowest practicable level". This concept is understood as such a level of risk, for the achievement of which the control action is possible and expedient and will not lead to bankruptcy of the company. The process of developing such measures requires the mobilization of all the intellectual resources of the airline, and this is an ongoing process. Almost all aircraft commanders and engineers of the airline are involved in this process. The results of this work for each hazardous situation are reflected in a summary report, the form of which was developed by the airline's specialists themselves (Table 1.2).

Table 1.1 - Example of a form for a summary report on a hazardous situation

<table>
<tr><td colspan="7">Hazardous situation summary report No. 12-5</td></tr>
<tr><td colspan="3">Description of the dangerous situation: Loss of spatial orientation in a snow whirlwind</td><td colspan="4">Danger: aircraft in motion</td></tr>
<tr><td>Developer:</td><td>Approved by:</td><td>Revision number 2</td><td colspan="4">What kind of work can lead to a dangerous situation: When performing all types of aviation work</td></tr>
<tr><td colspan="7">Risk assessment</td></tr>
<tr><td>People: C3</td><td colspan="2">Environment:C1</td><td colspan="2">Property:C2</td><td>Reputation:C2</td><td>Overall rating:24</td></tr>
<tr><td colspan="7">Risk analysis</td></tr>
<tr><td>Threats</td><td>Threat management</td><td>Aggravating factors</td><td></td><td></td><td>Aggravating factors</td><td></td></tr>
</table>

The summary report contains in a concentrated form all the information necessary for the control and analysis of risk.

The summary reports are a tool that allows you to form plans of measures to reduce risks for production units and the airline as a whole, as well as to exercise effective control over their implementation.

SkyUp Airlines LLC is a Ukrainian charter and low-cost airline, which began its operation in May 2018.

Plans for the first year included concentrating on international charter flights to popular summer destinations, as well as scheduled flights within Ukraine and to several international destinations.

For the purposes of BP management in SkyUp Airlines, an indicator characterizing the level of flight safety in the airline is used - the number of aviation incidents per 1000 flights, and on the eve of the coming year, a “BP level monitoring screen” is prepared (Figure 1.7), on which the specified and control BP levels are applied and, accordingly, A green, yellow and red field is “colored”, in which [40]:

- if the value of the current PSU level does not exceed the control value, i.e. be in the green field, then the work is going on in the regular (planned) mode;

- if the value of the current power supply level exceeds the control value, i.e. goes to the yellow field, then an unscheduled BP analysis is performed. The results of the analysis are considered at an extraordinary meeting of the BP Committee, where drafts of managerial decisions are developed, which are in the competence of the CEO of the airline;

- if these measures are not enough, and the value of the current BP level goes into the red zone, i.e. exceeds the specified level, the problems are brought to the level of the President of the group of companies.

Of particular interest is the automated system for predicting and preventing aviation accidents of the SkyUp Airlines LCC of Companies.

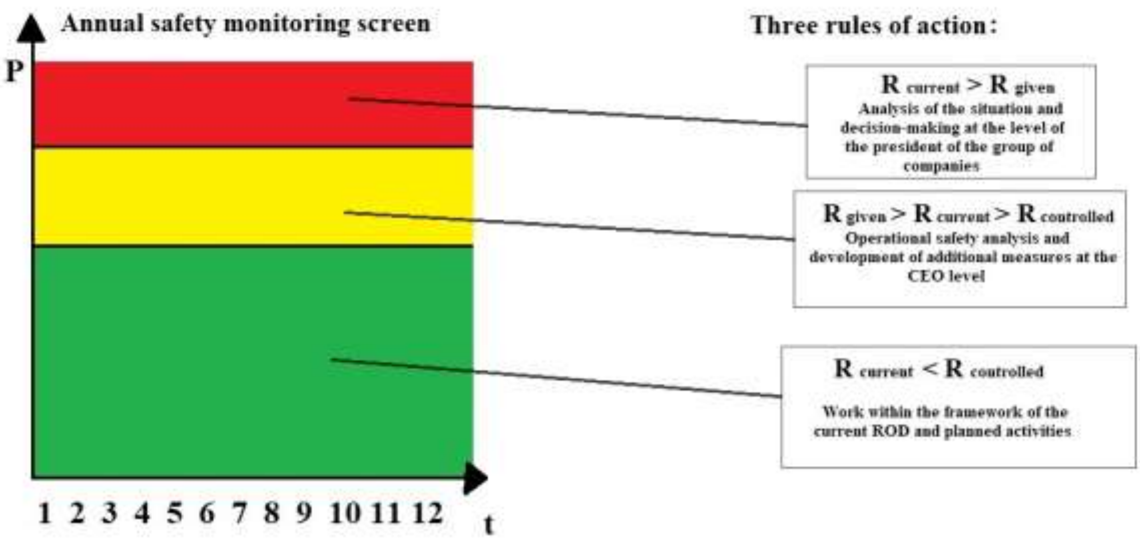


Figure 1.5 – Screen for monitoring the level of flight safety and rules of action

Where, ROD - regulatory operational documentation.

This system includes:

- assessment, short-term and long-term forecasting of risks;
- calculation of risks for each type of aviation event and total cost risk;
- identifies the factors of danger in the groups "Man", "Environment", "Machine";
- issues a recommendation to the airline's management on a set of management decisions from databases with the calculation of the level of prevented damage;
- calculation of residual risk by type of aviation event and total residual risk;
- monitoring of flight safety indicators.

Azur Air Ukraine, until October 2015 UTair-Ukraine, is a Ukrainian charter airline based at Boryspil International Airport. It used to be a subsidiary of Russian UTair Aviation.

In October 2015, it has been announced that tour operator Anex Tours would acquire UTair-Ukraine from UTair Aviation with the aim to rebrand it to Azur Air Ukraine as a leisure charter carrier. UTair Ukraine already shifted its focus from domestic services to leisure operations earlier and therefore phased out several planes. The sale and rebranding was confirmed shortly after. A few weeks later, Anex also bought the Russian Azur Air which the "new" Ukrainian Azur Air is now a sister company of.

The aircraft fleet contains 7 aircrafts, as 3 Boeings 737-800, 1 Boeing 757-300, 3 Boeings 767-300ER.

The airline's SMS was implemented in three stages:

1. In 2008, the implementation of the SMS Implementation Quality Assurance Plan began. The first version of SMS was developed based on ICAO SMM 2006.

2. In 2009 the SMS was revised and the second version was developed.

3. In 2011, in accordance with the second edition of the ICAO SMM, the airline's SMS was revised again.

The main goals of the airline in the field of flight safety:

- identification of hazards;
- taking corrective actions;
- ensuring constant monitoring;
- continuous improvement of the SMS to ensure the efficiency and effectiveness of service delivery.

Evaluation and decision-making to reduce risks to flight safety is carried out using the risk assessment matrix (Figure 1.8), while:

1. If the risk is acceptable, then business leaders can make decisions without developing corrective actions.

2. When the risk is controlled, the analysis of violations, corrective actions and risk control is the responsibility of the Director for Flight Safety and Quality.

3. If the level of risk is unacceptable, the responsibility for making decisions on risk mitigation measures rests with the CEO of the airline.

	Risk assessment matrix							
Consequences of events				The frequency of occurrence of consequences (per flight hour)				
Level	(People)	S (Safety)	E (Ecology)	A	B	C	D	E

				Out of airline	10^{-7}	10^{-6}	10^{-5}	10^{-4}
1	Minor injuries	Weak effect	Weak consequences					
2	Disability up to 3 months	Minor effect	Small consequences	Acceptable risk				
3	Disability up to 6 months	Substantial effect	Local consequences			Controlled risk		
4	Disability for work more than 6 months	Emergency effect	Serious consequences				Unaccepta-ble risk	
5	Death of people	Catastrophic effect	Major consequences					

Figure 1.6 - Matrix of risk assessments of JSC «Azur Air Ukraine»

Motor Sich is a Ukrainian airline based in Zaporizhzhia, Ukraine. It operates passenger and cargo services, including charter and scheduled flights. Its main base is Zaporizhzhia International Airport.

The company operates a fleet of 10 aircraft and 8 helicopters performing regular international and domestic passenger flights, passenger and cargo charter flights, as well as special flights supporting the activities of the parent company.

The materials show that in the SMS, the accident risk factors management algorithm provides for:

1. Assessment of the acceptability of risk based on the results of the assessment;

2. Synthesis of targeted control actions based on the results of private risk assessment by groups of factors (Figure 1.9).

Figure 1.7 - Algorithm for the management of risk factors of aviation accidents in the flight safety management system of the Motor Sich Airlines.

The airline Motor Sich Airlines has developed and put into operation an automated flight safety monitoring system AFSMS and an automated flight safety forecasting system AFSFS.

In the automated system for monitoring the level of flight safety "AFSMS", the probability of a catastrophe is assessed by the number of aviation events that occurred in the airline, starting with incidents, taking into account causal factors.

The automated system for predicting the level of flight safety "AFSFS" allows forecasting the level of flight safety by the frequency of incidents and by assessing the likelihood of an accident for the coming month and year.

Wizz Air, legally incorporated as Wizz Air Hungary Ltd is a European ultra low-cost airline with its head office in Budapest. The airline serves many cities across Europe, as well as some destinations in North Africa and the Middle East. It has the largest fleet of any Hungarian airline, although it is not a flag carrier, and currently serves 44 countries. Its Jersey-based parent company, Wizz Air Holdings plc, is listed on the London Stock Exchange and is a constituent of the FTSE 250 Index. As of 2020, the airline has its largest base at Budapest Airport and Luton Airport with 70 destinations. In 2019 the airline transported 39.8 million passengers.

Wizz Air began operations with a fleet of Airbus A320 jets.

As of September 2020, the Wizz Air fleet consisted of the following aircraft; A320-200, A320neo, A321-200, A321neo, A321 XLR, A330-200F (Wizz Air Hungary Ltd: [site]. URL: https://www.planespotters.net/airline/Wizz-Air-Holdings-Plc).

To collect, systematize, and analyze data on hazard factors by a proactive method, the airline has created an automated risk factor management system "RiskManager" (Figure 1.10). This program includes the calculation of the level of risks for all events (also after the adoption of corrective measures) after the automatic determination of the degree of probability of hazard factors and their input by experts in the areas of activity.

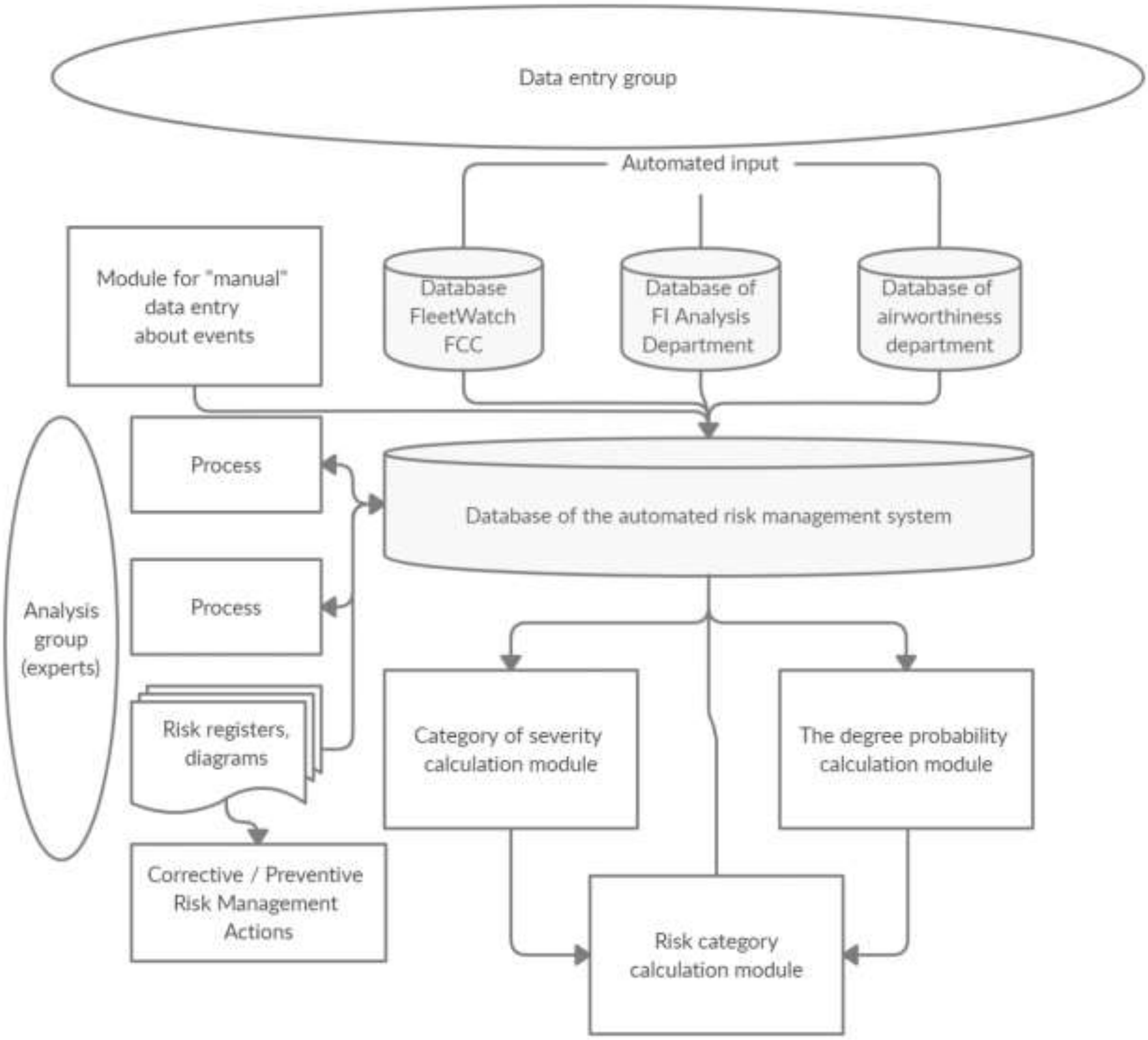


Figure 1.8 - Simplified block diagram of ARMS "Risk Manager" functioning

The operating system for managing risk factors of Wizz Air includes three levels of management:

1. The “operational” level of risk factor management is carried out at the level of shift managers based on daily reports from employees and other information about events and threats (Figure 1.9). Information about events requiring the adoption of coordinated operational measures is sent to flight debriefing, which has the effect of constantly interrupting the chains of small events that can lead to serious

consequences. Risks, the growth trend of which cannot be reduced by operational measures, move to the "tactical" level.

"OPERATIONAL" LEVEL OF MANAGEMENT - DAILY RISK REGISTER			
Controlled hazards	Corr. actions	Responsible	Data
OH 0X79 + GH 069 7 16.01 Late equipping of the aircraft with household goods due to a shortage of personnel (SO-1 UOP S 0:08) + Processing of the aircraft with FOZh (M09 0:17)	The driver of the 6th brigade was late for work due to a breakdown of his personal car, until 11.00 5 brigades worked.	Service	18.01
11.01 in Kiev from 20:00 to 21:00 PRINT SERVER HANGING, INABILITY TO PRINT THE FLIGHT JOB	There was a jam in the printer from 20:45 to 23:34, engineers eliminated	IT	18.01
14.01 MC 72A BC B-734 VP-BQG, for maintenance. Time 07:43. Grounding has not been established on the aircraft.	ABOUT THE VIOLATION, THE HEAD IS INFORMED. Preventive work was carried out with the contractor.	Eng	18.01

Figure 1.9- Report of the "Operational" level of risk factor management

2. The "tactical" level of risk management is carried out at the level of the deputy general directors in the areas of activity (Figure 1.10). In the form of weekly monitoring, statistical review of risks for the month, quarterly analysis of risks, information comes from experts. Risks whose upward trend cannot be mitigated by corrective measures at the tactical level are transferred to the “strategic” level.

TACTICAL LEVEL	
G20-Violations on the Airborne Defense Complex	
Description of the risk	Loading of faulty equipment onto the aircraft, undersupply of dishes. Loading faulty equipment onto an aircraft may result in injury. Lack of the required amount of dishes can lead to a violation of passenger service technology.
Corrective actions	Complaints are being carried out with the on-board catering shops, comprehensive inspections are being carried out on board the aircraft. Defective equipment is withdrawn from circulation. Repair of existing carts, control of loading of the corresponding equipment.
Evaluation of the effectiveness of measures	The effectiveness is sufficient.

Conclusions	By the end of the year, the level of risk for this category decreased to an acceptable level, but nevertheless, to maintain the risks of this category in this state, constant monitoring and repair of the exchange fund of tableware. A stable downtrend was recorded. The effectiveness of corrective and preventive measures is sufficient.
Risk forecast	The most likely danger factors in the near future may be:
	1. Loading faulty equipment onto the aircraft, under-investment of dishes. Probability - 7
	2. Loading poor quality food. Probability - 2

Figure 1.10- Report of the "Tactical" level of risk factor management

3. The "strategic" level of risk factor management provides for periodic assessments of the results of statistical analysis, taking into account the accumulation of data for the expected changes in the airline's activities and making appropriate decisions at the highest level.

Thus, the considered automated programs operating within the SMS are effective systems that allow airlines to process a large amount of data in short time intervals. These systems allow assessing and predicting the level of flight safety, and, based on this information, help airlines to make further decisions on the management of flight safety.

When compiling a list of management decisions to reduce the risks of aviation events, the SMS of airlines do not take into account the criterion of minimum total costs.

1.3. Chapter 1 Conclusions

As a result of the study of information on the state of flight safety, theory and practice of managing the level of flight safety in airlines, the following conclusions can be drawn:

1. Airlines use various methods in SMS in terms of identification, analysis, and risk reduction of aviation events. Some of these stages are carried out in an automated manner using computer programs. Based on the experience gained in the application of SMS of aviation companies, it is advisable to develop a standard that includes the most effective methods. There is currently no such document. An SMS standard would be useful for airlines (which have less efficient SMS) in methodological improvements to the system

2. The SMS of airlines does not take into account the criterion of minimum total costs when developing measures to reduce the risks of aviation events.

The process of managing risk factors in the activities of airlines can be improved and be more effective from the point of view of ensuring the safety of flights and the economy of the airline, if the target optimal level of flight safety is determined based on the criterion of minimum total costs. This problem is an extreme one.

3. It is advisable to develop within the SMS a method for managing risk factors, the basis of which is the formation of measures that reduce the risk of aviation events, taking into account the provision of minimum total costs (balance of

costs) for ensuring flight safety and eliminating possible damage from aviation events.

4. It is necessary to develop a mathematical model of the total costs of ensuring flight safety and eliminating the consequences of aviation events in SMS, taking into account the effectiveness of measures to reduce the risk of aviation events.

CHAPTER 2. DEVELOPMENT OF A MATHEMATICAL MODEL OF TOTAL COSTS FOR PROVIDING THE SAFETY OF FLIGHTS AND ELIMINATION OF CONSEQUENCES OF AIRCRAFT EVENTS IN THE SAFETY MANAGEMENT SYSTEM OF AIRLINES

In the process of managing negative risk factors of aviation events, it is important to take into account the principle of maximum investment efficiency, according to which, with each portion of additional investments, the efficiency of the latter decreases after a certain level of investment.

In order to determine the optimal level of improving flight safety for airlines, this chapter provides the conclusion and analysis of the mathematical model of the total costs of airlines in SMS.

Total costs in SMS are understood as costs aimed at implementing measures to reduce the risks of aviation events and eliminate the consequences of expected damage from aviation events.

2.1. Determination of the risk formula for the implementation of aviation events

Aviation events in our work mean incidents, serious incidents, aviation accidents with fatalities (disasters) and without fatalities (accidents):

- an aircraft accident is an event that happened to an aircraft while using it for its intended purpose, and the implementation of this event led to the following consequences:

1) the person (or persons) who was on the plane (with whom the aviation event occurred) received bodily injury (excluding cases of damage caused by natural causes, cases when bodily harm was caused by persons whose presence on the aircraft was unlawful, cases of damage to oneself);

2) the structure of the aircraft is damaged, while the flight and technical characteristics of the aircraft deviate from the norm, there is a need to carry out repairs (to replace destroyed or damaged structural elements). Damage cases:

- only the engine, its auxiliary units, hoods, its failure;
- wingtips;
- antennas;
- braking devices;
- non-power elements of the glider;
- other elements, if the strength of the structure as a whole is not violated;
- tail rotor or main rotor bushings;
- fan installation;
- reducer;
- transmissions;
- parts of the main and tail rotor, if the load-bearing elements of the fuselage are not destroyed, do not belong to aviation accidents.

3) as a result of an accident, the aircraft disappears or is in an inaccessible place;

- aviation incident - an aviation event in which there is a slight deviation from the parameters of the normal functioning of support services, control, crew, aircraft, and is characterized by a slight increase in psychophysiological load on the crew, but did not lead to an accident.

- serious aviation incident - an aviation event in which there is a significant deviation from the parameters of the normal functioning of support services, control, crew, aircraft, and is characterized by a noticeable increase in psychophysiological load on the crew, but not leading to an accident or disaster.

When preparing proposals to improve flight safety, the entire structure of the airline is considered, including aviation personnel, aircraft fleet, and flight support services.

Various failures and deficiencies in the operation of the listed subsystems can lead to the occurrence of aviation events. The main considered parameter of the state of the system is flight safety, which is expressed through the probability of occurrence of aviation events. The main factors that negatively affect flight safety are human, technical, non-systemic.

Aviation events of the same type, which occur for the same (or different) reasons and lead to the same type of consequences, form a homogeneous stream of events that differ in time of occurrence.

To confirm the hypothesis about the distribution of aviation events according to Poisson's law, the statistics of aviation events with various aircraft were considered: 286 serious incidents, 51 accidents as a result of a rough landing, roll-out, landing in conditions below the operational meteorological minimum by factor - crew error (according to the international organization “Air claims World Aircraft Accident "). It was revealed using the Pearson criterion (chi-square) that aviation events are distributed according to Poisson's law with a probability of 0.68 for serious incidents, 0.71 for accidents. The argument in favor of the hypothesis of the distribution is the proximity of the values of statistical characteristics, such as the mathematical expectation and variance of the frequencies of occurrence of aviation events.

Considering this, the probability of the occurrence of aviation events, which are distributed according to Poisson's law, is determined by the formula:

$$P(AC) = \lambda_{AC} \cdot T, \tag{2.1}$$

- λ_{AC} is the intensity of the stream of homogeneous aviation events, hour;
- T is the flight time of the aircraft, hour.

The flow of aviation events is estimated by the flow parameter. To assess homogeneous events, the intensity of the flow of events is used - the number of events per unit time and has the dimension [$hour^{-1}$].

Three approaches can be used to calculate the magnitude of individual flow parameters (or flow rates) of aviation events:

The values of the flow parameter can be determined on the basis of the probabilistic criterion for the occurrence of accidents and the statistical ratios of the parameters of the flows of aviation events given by the ICAO.

The λ_{AC} values can be taken equal to the corresponding probabilities of occurrence of special situations in the expected operating conditions of aircraft established by the Aircraft Airworthiness Standards, provided that during the design these requirements were met and confirmed by tests at the manufacturing plant at the start of serial production.

Any aviation event can be the result of several factors (causes). Each factor has its share in the occurrence of an aviation event. A particular aviation event has its own factors that represent a complete group of events. An aviation event factor fraction is nothing more than the conditional likelihood that an aviation event occurs as a result of that factor. The designations for conditional probabilities are shown in Table 2.1.

Probability does not measure the severity of the consequences of events There is uncertainty in assessing the severity of possible consequences, which is compensated by the risk matrix.

The flow parameters for each specific type of aviation event are calculated based on existing classifiers and enterprise statistics.

Table 2.1 - Designations of the conditional probabilities of occurrence of aviation events for certain factors

AE	Factors (causes) of aviation events						
	F_1	F_2	F_3	…	F_{a}	…	F_g
AE_1	P(F_1/AE_1)	P(F_2/AE_1)	P(F_3/AE_1)	…	P(F_a/AE_1)	…	P(F_g/AE_1)

AE_2	$P(F_1/AE_2)$	$P(F_2/AE_2)$	$P(F_3/AE_2)$	…	$P(F_a/AE_2)$	…	$P(F_g/AE_2)$
…	…	…	…	…	…	…	…
AE_j	$P(F_1/AE_j)$	$P(F_2/AE_j)$	$P(F_3/AE_j)$	…	$P(F_a/AE_j)$	…	$P(F_g/AE_j)$
…	…	…	…	…	…	…	…
AE_m	$P(F_1/AE_m)$	$P(F_2/AE_m)$	$P(F_3/AE_m)$	…	$P(F_a/AE_m)$	…	$P(F_g/AE_m)$

$\sum_{a=1}^{g} P(F_a/AE_j) = 1$; ꝟj; j=$\overline{l,m}$; j=$\overline{l,g}$.

Each aviation event, even caused by one and the same cause (or several reasons), will occur in its own way and will lead to its own damage. Therefore, from the statistical data, it is necessary to obtain for this factor the average value of the expected damage as the sample mean or the arithmetic mean. These data are summarized in table 2.2.

Table 2.2 - Designations of the average expected damage from aviation events

AE	Average damage from an aviation event by factor a						
	F_1	F_2	F_3	…	F_a	…	F_g
AE_1	$\overline{E_{11}}$	$\overline{E_{12}}$	$\overline{E_{13}}$	…	$\overline{E_{1a}}$	…	$\overline{E_{1g}}$
AE_2	$\overline{E_{21}}$	$\overline{E_{22}}$	$\overline{E_{23}}$	…	$\overline{E_{2a}}$	…	$\overline{E_{2g}}$
…	…	…	…	…	…	…	…
AE_j	$\overline{E_{j1}}$	$\overline{E_{j2}}$	$\overline{E_{j3}}$	…	$\overline{E_{ja}}$	…	$\overline{E_{jg}}$
…	…	…	…	…	…	…	…
AE_m	$\overline{E_{m1}}$	$\overline{E_{m2}}$	$\overline{E_{m3}}$	…	$\overline{E_{ma}}$	…	$\overline{E_{mg}}$

The damage from an aviation event per aircraft will be equal on average to $\overline{E_{AE}}$ and is determined by the formula:

$$Y = \lambda_{AC} \ T \ \overline{C_{AE}}, \qquad (2.2)$$

where $\overline{C_{AE}}$ – is the average damage of an aviation event.

Chapter 1 notes that the airline's own costs in an aviation event are 2 or 3 times higher than insurance payments. Taking this into account, the work considers damage without taking into account insurance and the level of the deductible (to simplify the problem and as a first approximation).

Damage is associated with risk. In modern terminology, the concept of "risk" has a different definition.

For example, in the first edition of the ICAO SMM (2006, Doc 9859 AN / 460), risk was defined as “the combination of the probability of a hazardous event and the severity of the potential consequences”. In the second edition of the ICAO SMM, safety risk is “an assessment of the consequences of a hazard, expressed in terms of predicted probability or severity, with the worst foreseeable situation as the benchmark”. In the third edition of the ICAO SMM, risk is “predicted probability and severity of consequences”.

According to ICAO Doc 9859 risk is the assessed potential for adverse consequences resulting from a hazard. It is the likelihood that the hazard's potential to cause harm will be realized.

According to Regulation (EU) 2017/373 risk means the combination of the overall probability or frequency of occurrence of a harmful effect induced by a hazard and the severity of that effect.

We can consider risk as the assessment, expressed in terms of predicted probability and severity, of the consequence(s) of a hazard taking as reference the worst foreseeable situation; the likelihood of harm to the life or health of citizens, property of individuals or legal entities, state or municipal property, the environment, life or health of animals and plants, taking into account the severity of this harm.

Thus, the risk of an aviation event by one factor will be determined by the formula:

$$R = \lambda_{AE} \cdot T \cdot P\,(F/AE) \cdot \overline{E_{AE}}\,, \tag{2.3}$$

where P (F / AE) is the conditional probability that an aviation event occurred due to a specific factor F.

The most important characteristic of a random variable is its mathematical expectation - the average value around which all its possible values are grouped.

The expectation of the risk of AQ occurrence will be determined by the expression:

$$R_j = P(AE_j) \cdot P(F_1/AE_j) \cdot \overline{E_{j1}} + P(AE_j) \cdot P(F_1/AE_j) \cdot \overline{E_{j2}} + \cdots +$$

$$P(AE_j) \cdot P(F_g/AE_j) \cdot \overline{E_{jg}} = P(AE_j) \sum_{a=1}^{g} C_{ja} \cdot P(F_a/AE_j) =$$

$$\lambda_j \cdot T \sum_{a=1}^{g} \overline{C_{ja}} \cdot P(F_a/AE_j) \tag{2.4}$$

Considering that the number of types of aviation events is m, then the total risk of occurrence of m aviation events (which are already heterogeneous in relation to each other (for example, serious incidents and disasters)) will be determined by the expression:

$$R_{AE} = \sum_{j=1}^{m} R_j = \sum_{j=1}^{m} \lambda_j \cdot T \cdot \sum_{a=1}^{g} \overline{E_{ja}} \cdot P(F_a/AE_j) \tag{2.5}$$

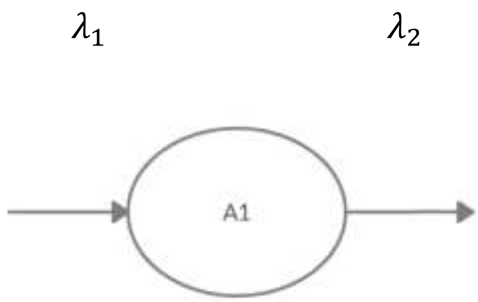
If the aircraft fleet of airlines includes a certain number of aircraft and if we take q - a specific type of aircraft $q = \overline{1, v}$, then the risk of aviation events will be determined by the formula:

$$R_{AE} = \sum_{j=1}^{m} R_j = \sum_{q=1}^{m} \lambda_j \cdot \sum_{a=1}^{v} T_q \cdot \sum_{a=1}^{g} \overline{E_{ja}} \cdot P(F_a/AE_j) \tag{2.6}$$

Risks used in the work are classified by types of aviation events (risks of catastrophes, accidents, serious incidents, incidents), by types of factors (risks of aviation events caused by technical, human, non-systemic factors), according to the degree of acceptability, which depends on the magnitude of the probability and expected damage, in accordance with ICAO SMM (acceptable, acceptable, unacceptable).

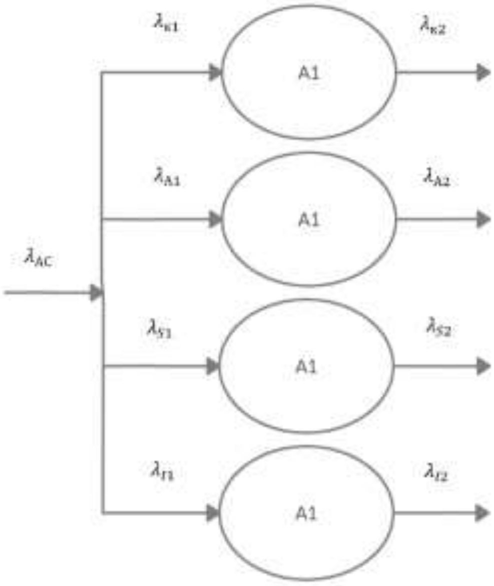
2.2. Probability of preventing aviation events

Suppose that within the SMS, an action has been implemented to reduce the risk of an aviation event (Figures 2.1; 2.2). Measures to reduce the risk of aviation events are a set of actions (actions) aimed at reducing (in some cases - preventing) the level of risks of aviation events. Before the implementation of the measure, the intensity of the flow of aviation events is λ_1, after implementation - λ_2:



A_1 - an arrangement to reduce the risk of an aviation event.

Figure 2.1 - Aviation event prevention graph



A - disaster risk reduction arrangement;

A_{A1} - arrangement to reduce the risk of accidents;

A_{S1} - arrangement to reduce the risk of incidents;

A_{11}- arrangement to reduce the risk of serious incidents.

Figure 2.2 - Graph of prevention of aviation events

If $\lambda_2 < \lambda_1$, then as a result of the implementation of the measure, a part of aviation events is filtered, parried, destroyed. If $\lambda_2 = \lambda_1$ then the activities do not work, all aviation events happen.

Risk mitigation measures are characterized by the likelihood of preventing aviation events. The probability of preventing aviation events is the ratio of the intensity of the flow of aviation events of a certain type after the implementation of measures to the intensity of the flow of these events, which was before the implementation of measures:

$$P_{pr} = \frac{\lambda_{pr}}{\lambda_{general}} \qquad (2.7)$$

where $\lambda_{general}$ is the initial flow rate of the j-ro type of aviation events before the implementation of measures to reduce risks; λ_{pr} is the intensity of the flow of aviation events of the j-ro type, taking into account preventive measures.

The flow rates of prevented aviation events are predictive values and are calculated by the expert method.

There can be several risk reduction measures for each factor. One event can prevent several factors.

Symbols for the probability of preventing aviation events following the implementation of measures to reduce the risk of aviation events are shown in Table 2.3.

Table 2.3 - Designations of the probabilities of preventing aviation events following the implementation of measures to reduce the risks of aviation events.

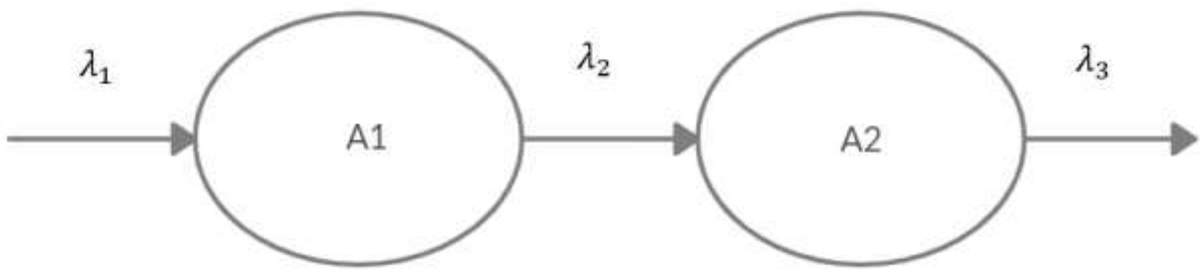
Factors of aviation events	Factors (causes) of aviation events					
	A_1	A_2	…	A_X	…	A_Z
F_1	P(A_1/F_1)	P(A_2/F_1)	…	P(A_X/F_1)	…	P(A_Z/F_1)
F_2	P(A_1/F_2)	P(A_2/F_2)	…	P(A_X/F_2)	…	P(A_Z/F_2)
F_3	P(A_1/F_3)	P(A_2/F_3)	…	P(A_X/F_3)	…	P(A_Z/F_3)
…	…	…	…	…	…	…
F_a	P(A_1/F_a)	P(A_2/F_a)	…	P(A_X/F_a)	…	P(A_Z/F_a)
…	…	…	…	…	…	…
F_g	P(A_1/F_g)	P(A_2/F_g)	…	P(A_X/F_g)	…	P(A_Z/F_g)

If several risk mitigation measures are implemented (Figures 2.3; 2.4), with $\lambda_1 = 10, \lambda_2 = 8, \lambda_3 = 4$, then the probability of preventing the arrangement A_1:

$$P_{prA1} = \frac{4}{5}, \quad (2.8)$$

probability of preventing an arrangement A_2:

$$P_{prA2} = \frac{4}{8}, \quad (2.9)$$



A_1 - first event to reduce the risk of aviation arrangements;

A_2 - second event to reduce the risk of aviation arrangements;

λ_1 - the intensity of the flow of aviation events before the implementation of arrangements A_1 , A_2;

λ_2- the intensity of the flow of aviation events after the implementation of arrangements A_1 and before implementation A_2;

λ_3 - the intensity of the flow of aviation events after the implementation of arrangements A_1 , A_2;

Figure 2.3 - Graph of prevention of two aviation events

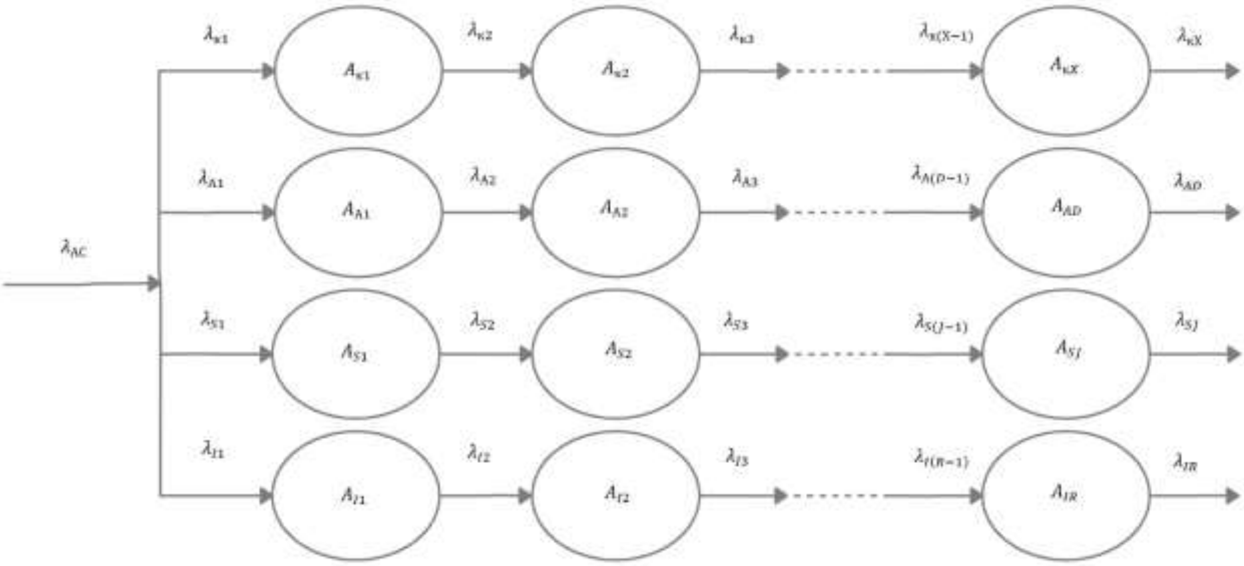
Overall probability of prevention following the implementation of arrangements A_1 , A_2:

$$P_{general\,pr}=P_{prA1} \cdot P_{prA2}= \frac{8}{10} \cdot \frac{4}{8} = \frac{2}{5} \tag{2.10}$$

Thus, if there are several activities, then the costs of implementing activities $\overline{C_n}$ to reduce risks will be summed up, and the resulting probability of prevention P_{pr} will be equal to the product of the probabilities of preventing arrangements $P_{pr\ n}$ following the implementation of each event that reduces the risk of events:

$$\overline{C} = \sum_{n=1}^{i} \overline{C_n} \tag{2.11}$$

$$P_{pr} = \prod_{n=1}^{i} P_{prn} \tag{2.12}$$



A_1 - first event to reduce the risk of aviation arrangements;

A_2 - second event to reduce the risk of aviation arrangements;

$\lambda_{\kappa(X-1)}$ - the intensity of the flow of disasters before the implementation of the arrangement $A_{\kappa X}$

$\lambda_{\kappa X}$- the intensity of the flow of disasters before the implementation of the arrangement $A_{\kappa X}$

$\lambda_{A(D-1)}$- intensity of the flow of accidents before the implementation of the arrangement A_{AD};

λ_{AD}- the intensity of the flow of accidents after the implementation of the arrangement A_{AD};

$\lambda_{S(J-1)}$ - intensity of the flow of serious incidents before the implementation of the arrangement A_{SJ};

λ_{SJ} - the intensity of the flow of serious incidents after the implementation of the arrangement A_{SJ};

$\lambda_{I(R-1)}$ - the intensity of the flow of incidents before the implementation of the arrangement A_{IR};

λ_{IR} - the intensity of the flow of incidents after the implementation of the arrangement A_{IR}.

Figure 2.4 - Graph of prevention of four types of aviation events

The resulting probability of prevention for aviation events is:

$$P(A_X/F_E)_{result} = \prod_{X=1}^{Z} P(A_X/F_a); \tag{2.13}$$

If the probability of preventing aviation events as a result of the implementation of measures to reduce the risks of aviation events is zero, then the measures are ineffective, all events in this case are implemented. If the probability of preventing aviation events as a result of the implementation of measures to reduce the risks of aviation events tends to unity, respectively, the measures are effective.

2.3. Determination of the formula for the risk of aviation events taking into account the probability of preventing aviation events

The likelihood of prevention is closely related to the risk of an aviation accident.

Taking into account (4), when implementing measures aimed at reducing the risk of aviation events, the total risk value for all events will be:

$$\acute{R}_{AE} = \left[\sum_{j=1}^{m} \lambda_j \cdot \sum_{q=1}^{v} T_q \cdot \sum_{a=1}^{g} \overline{C_{ja}} \cdot P(F_a/AE_j)\right] \cdot \left[1 - \prod_{X=1}^{Z} P(A_X/F_a)\right] \tag{2.14}$$

Reducing the risk of aviation events from the implementation of preventive measures:

$$\Delta R_{AE} = R_{AE} - R_{AE};\ \Delta R_{AE} = \left[\left[\sum_{j=1}^{m} \lambda_j \cdot \sum_{q=1}^{v} T_q \cdot \sum_{a=1}^{g} \overline{C_{ja}} \cdot P(F_a/AE_j)\right] \cdot \left[\prod_{X=1}^{Z} P(A_X/F_a)\right]\right]$$

(2.15)

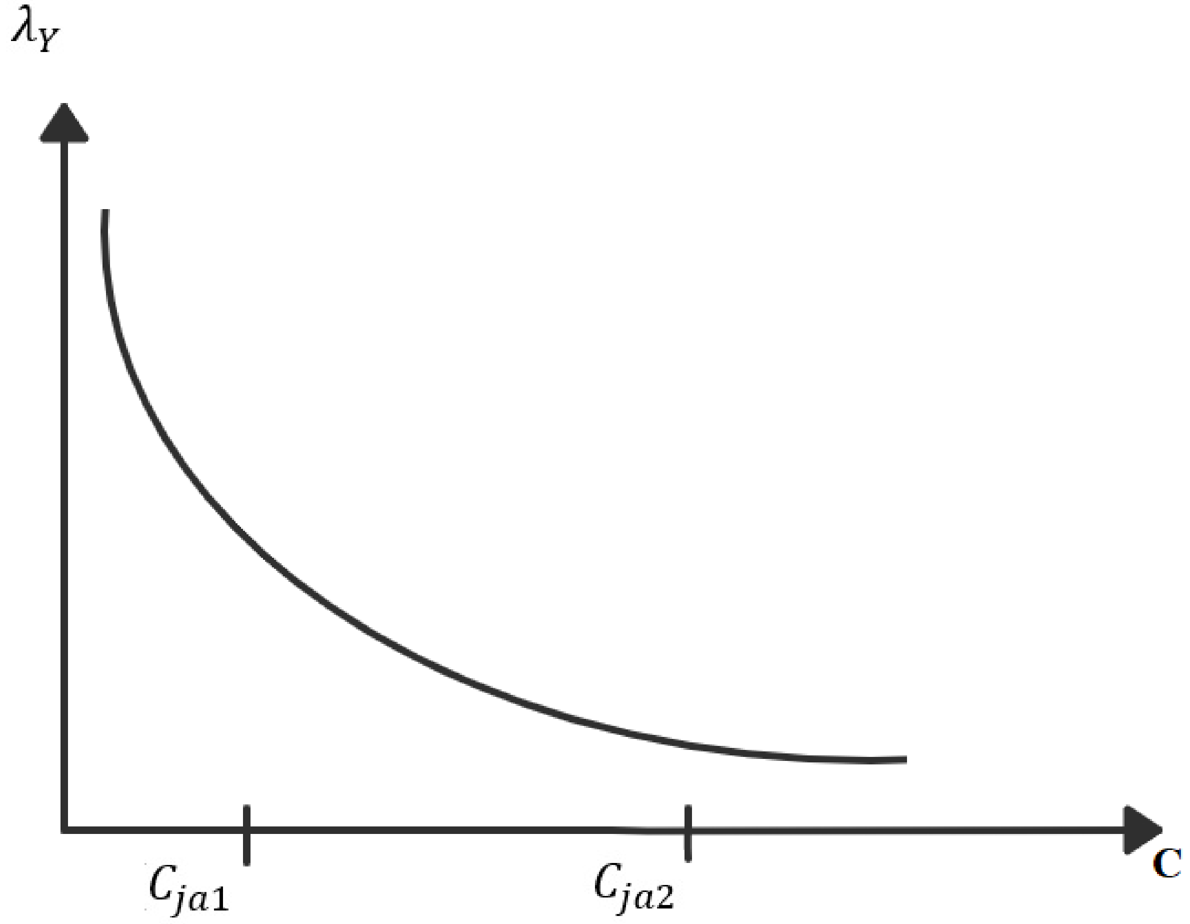
The choice of specific preventive measures can be made based on the Pareto principle. To do this, it is necessary to calculate the risks of aviation events, sort and select those that will most effectively affect the reduction of the overall risk:

$$\max_{o\epsilon m,q\epsilon v,a\epsilon g} R = max\left[\sum_{j=1}^{m} \lambda_j \cdot \sum_{q=1}^{v} T_q \cdot \sum_{a=1}^{g} \overline{\text{C}_{ja}} \cdot P(F_a/AE_j)\right]$$

(2.16)

With a significant amount of statistical data, it is advisable to move to a continuous assessment of damage and the risk of its implementation from aviation accidents and incidents.

Figure 2.5 shows an example of the dependence of the frequency of occurrence of an aviation event (and, as a consequence, material damage) λ_Y on the amount of damage from aviation events for a particular aviation enterprise.



C_{ja1}, C_{ja2} - disaster damages

Figure 2.5 - Dependence of the frequency of occurrence of aviation events on the amount of damage resulting from the implementation of an aviation event

The damage caused by an aviation event, such as a catastrophe, within the interval $[C_{ja1}, C_{ja2}]$ will be given by the expression:

$$Y = P(AE_j) \int_{C_{ja1}}^{C_{ja2}} P(F_a/AE_j) d\overline{C_{ja}} \quad (2.17)$$

Then the total risk of an aviation event occurring when preventive measures are introduced for a combination of reasons for the entire aircraft fleet:

$$R' = \lambda_j \sum_{q=1}^{v} T_q \cdot \int_{C_{ja1}}^{C_{ja2}} P(F_a/AE_j) d\overline{C_{ja}} \cdot \left[1 - \prod_{X=1}^{Z} P(A_X/F_a)\right]$$

(2.18)

Thus, formulas for calculating the risk of aviation events have been obtained, taking into account all types, intensities, damages, causes of events and the probability of prevention with a discrete and continuous distribution of damage. These formulas are necessary to build a mathematical model of the total costs in the airline's SMS.

2.4. Determination of the dependence of the amount of costs for measures that reduce the risk of aviation events on the probability of preventing aviation events

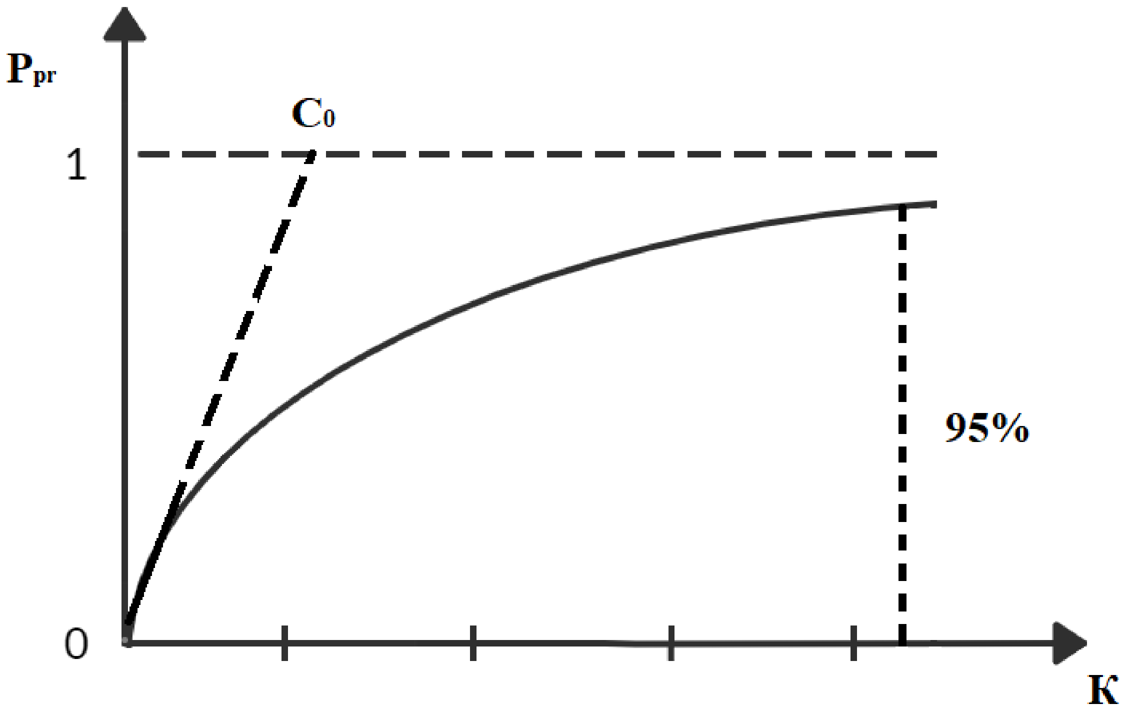
The ICAO SMM addresses the relationship between SMS and the quality management system. Integration of these systems provides an “orderly approach” to monitoring and control of processes aimed at identifying safety hazards and their consequences, monitoring the correct functioning of systems, identifying the need to improve them in the event of deviations”.

According to the interstate standard GOST ISO 9000-2011 “Quality management systems. Fundamentals and vocabulary” any activity that uses resources to transform inputs into outputs can be considered a process, therefore, improving safety can be viewed as a process (Figure 2.6).

Figure 2.6 - Improving the level of flight safety as a process

At present, the dependence of the value of the risk of an adverse event (successful outcome of the flight) on the cost of ensuring safety (for example, the cost of creating a new technology), characterized by a certain level of risk, has been studied and is a power function for any reason.

The dependence of the probability of preventing aviation events on the costs of measures that reduce the risk of aviation events has the form shown in Figure 2.7.



C_o- process constant characterizing the rate of change in the process;

Cost - flight safety costs;

P_{pr} - probability of preventing aviation events.

Figure 2.7 - Dependence of the probability of prevention on investments in measures that reduce the risk of aviation events

The graph is built on the basis of processing the data given in Chapter 4. The dependence is determined by the formula:

$$P_{pr} = 1 - \mathrm{e}^{\frac{Cost}{C_o}} \qquad (2.19)$$

when Cost=0, P_{pr} ⟶0, when Cost=∞, P_{pr} ⟶1,

where $P_{пр}$ - probability of preventing aviation events; C_o - process constant characterizing the rate of change of the process (increasing flight safety).

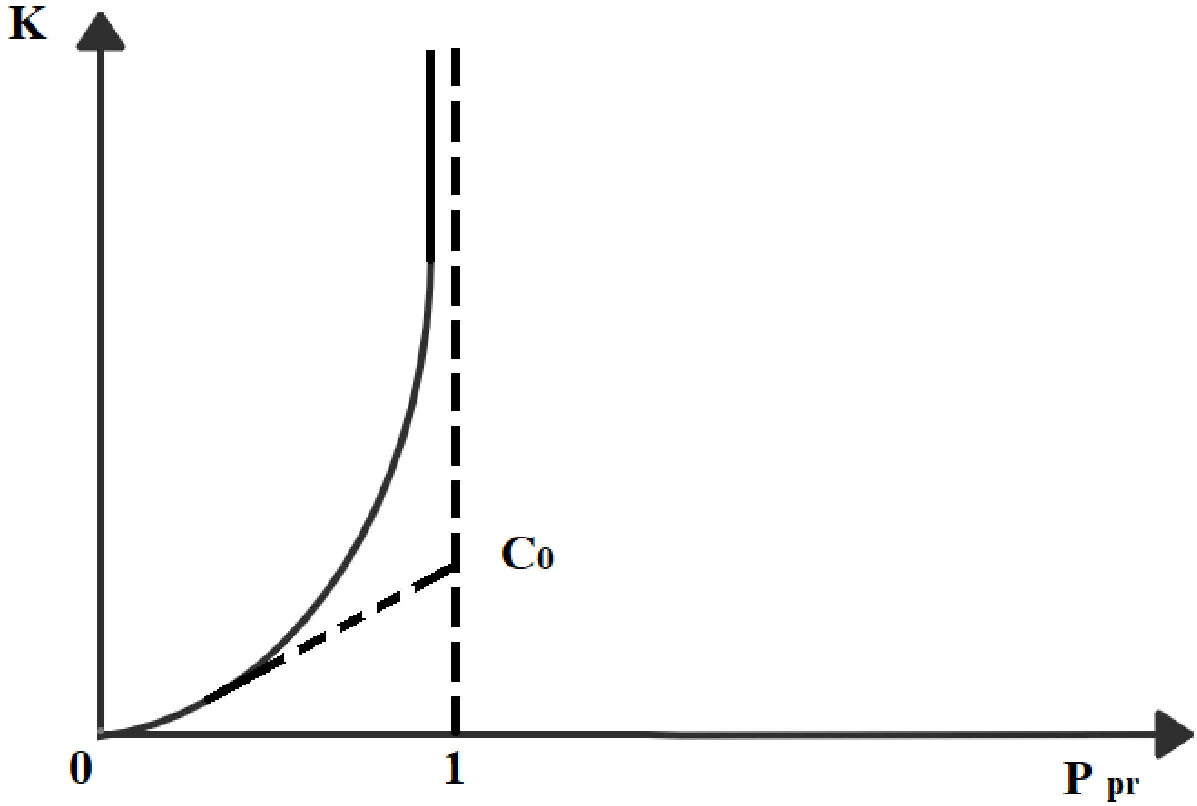
As a characteristic of an exponential process (a change in the probability of prevention depending on the cost of ensuring flight safety), the work considers a constant of the process, which determines the amount of funds invested in ensuring flight safety, as a result of which the process of increasing the level of flight safety, determined by the exponential, reaches 95% level asymptotes P_{pr} ⟶1. A lower C_o value means financial management and the most effective SMS.

The process constant is subtangent and is determined analytically and graphically. The process reaches 95% of the asymptote level after (3+5) C_o.

The inverse formula for the costs of events is:

$$Cost = -C_o \ln(1 - P_{pr}) \qquad (2.20)$$

Dependence is shown in Figure 2.8.



C_o- process constant characterizing the rate of process change;

Cost - is the cost of ensuring flight safety;

P_{pr} - probability of preventing aviation events.

Figure 2.8 - Dependence of investments in measures to reduce the risk of aviation events on the probability of preventing aviation events

In order to ensure or improve the safety of flights, airlines can develop and apply various measures, aimed at eliminating human, technical and non-systemic factors, for example:

- improvement of training simulators;

- improving the quality of professional training of flight personnel, personnel, engineering services;

- modernization or creation of new airborne and ground flight support facilities;

- improvement of flight and technical operation of aviation equipment;

- improvement of the technology of maintenance and repair of aviation equipment;

- improving the operational and technical characteristics of aviation technology;

- clarification or change of instructive, regulatory documents;

- organizational arrangements;

- introduction of automated control systems.

Arrangements can, in turn, be subdivided into more detailed ones. Cost formula for all activities:

$$Cost_{AE} = -\sum_{X=1}^{Z} \sum_{a=1}^{g} C_{oXa} \ln(1 - (P(A_X/F_a)) \qquad (2.21\ )$$

The effectiveness of measures to reduce the risk of aviation events can be assessed by the slope coefficient of the tangent to the graph:

$$\frac{dP_{pr}}{dCost} = \frac{d(1 - \mathrm{e}^{\frac{Cost}{C_o}})}{dCost} = \frac{1}{C_o} \cdot \mathrm{e}^{\frac{Cost}{C_o}}$$

(2.22)

$$\lim_{\mathrm{Cost} \to \infty} \frac{1}{C_o} \cdot \mathrm{e}^{\frac{Cost}{C_o}} = 0$$

(2.23)

If we assume that costs in the amount of $Cost_1$ are invested in arrangement A, then additional funds are invested in the amount of $Cost_2$, then the rate of change in the effectiveness of arrangement A with an increase in financial investments in them will be equal to:

$$\Delta P_{pr} = \mathrm{e}^{\frac{Cost_1}{C_o}} - \mathrm{e}^{\frac{Cost_2}{C_o}}$$

(2.24)

or

$$\Delta Cost_{pr} = C_o ln \frac{(1 - P_{pr2})}{(1 - P_{pr1})}$$

(2.25)

With an increase in financial investments in preventive measures, flight safety will increase, but the effectiveness of additional investments in measures may be lower than with the initial investment up to a certain level $P_{\text{пр}\, opt}$. It is important to determine the value of $P_{pr\, opt}$ from which the investment efficiency will decrease.

2.5. Determination of the optimal probability of preventing aviation events based on the criterion of minimum total costs

The use of the economic criterion in managing the risk factors of aviation events is determined by the ICAO requirement to maintain a balance of resources for ensuring flight safety and organizing production. The search for a so-called "compromise" between the two components is possible on the basis of the criterion of minimum total costs, the achievement of which means a balance between the amount of costs for eliminating possible damage from aviation events and for measures aimed at preventing damage. Deviation from the minimum total cost may mean unreasonable costs or insufficient resources allocated to ensure flight safety. The solution to this dilemma involves the following goals:

P$\longrightarrow min; R \longrightarrow min.$

In this case, the search for the optimal value of the level of flight safety should be carried out taking into account the efficiency parameter (in this case, the probability of preventing aviation events), which characterizes the level of reducing the risks of aviation events (the effectiveness of measures) and the cost of measures.

The probability of preventing aviation events characterizes the quality of the flight safety management system.

A certain proportion between the total cost and the probability of prevention will provide the greatest efficiency in ensuring flight safety. Taking this into account, $P_{пр}$ was taken as the optimization parameter, the optimization criterion is the minimum total costs. The probability of preventing aviation events and the minimum total costs are determined for each type of aviation event. From this, an appropriate classification of the criteria for minimum total costs is established.

With the known formulas for investments in ensuring flight safety and the risk of the implementation of aviation events, the total costs will be determined by the formula (at discrete values):

$$C_{gen} = R' + Cost =$$
$$= \left[\sum_{j=1}^{m} \lambda_j \cdot \sum_{q=1}^{v} T_q \cdot C_{ja} \cdot P(F_a/AE_j)\right] \cdot \left[1 - \prod_{X=1}^{Z} P(A_X/F_a)\right]$$
$$- \sum_{X=1}^{Z} C_{0\,Xa} \ln(1 - P(A_X/F_a)$$

(2.26)

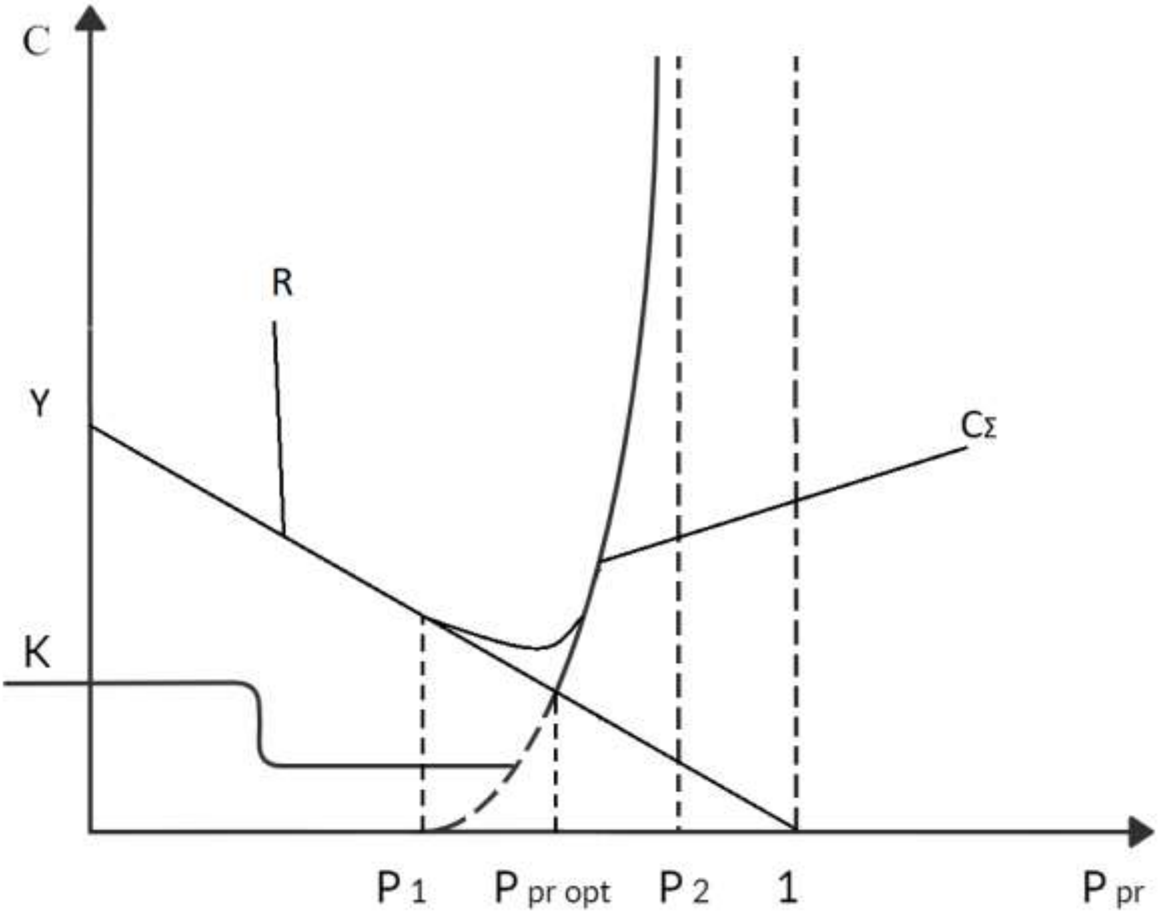
a = const

The mathematical model of total costs (7) underlies the method for optimizing the process of managing risk factors of aviation events based on the criterion of minimum total costs.

The mathematical model of total costs and the criterion of minimum total costs work under the condition 0≤P(M_X/Φ_a)<1; R, R'>0. The extremum point is determined by the formula:

$$\sum_{X=1}^{Z} C_{0Xa} \cdot \frac{1}{1-(P(A_X/F_a))^2} > 0 \quad (2.27)$$

Interval (P_1 $P_{\text{пр}\, opt}$) is the the desired level of increasing flight safety, ensuring the minimum total costs. Thus, the point $P_{pr\, opt}$, at which the airline's costs are minimal has been determined (Figure 2.9). Dependences of total costs on risk and investments in flight safety are shown in Figures 2.10, 2.11. Both graphs are plotted using the data provided in Chapter 4.



C - SMS costs;

C_{Σ} - total costs;

Cost - flight safety costs;

$P_{pr\, opt}$ - оптимальная вероятность предотвращения авиационных событий;

P_1, P_2- the probability of preventing aviation events, initial and target, respectively;

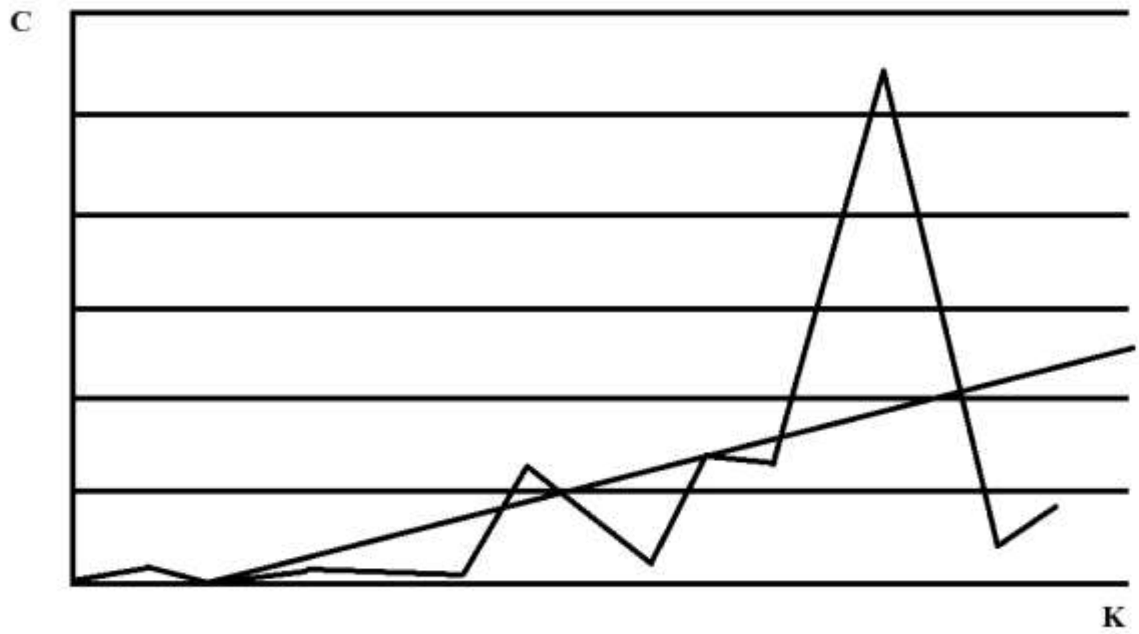
P_{pr} - the likelihood of preventing aviation events;

R - the risk of aviation events;

Y - damage from aviation events.

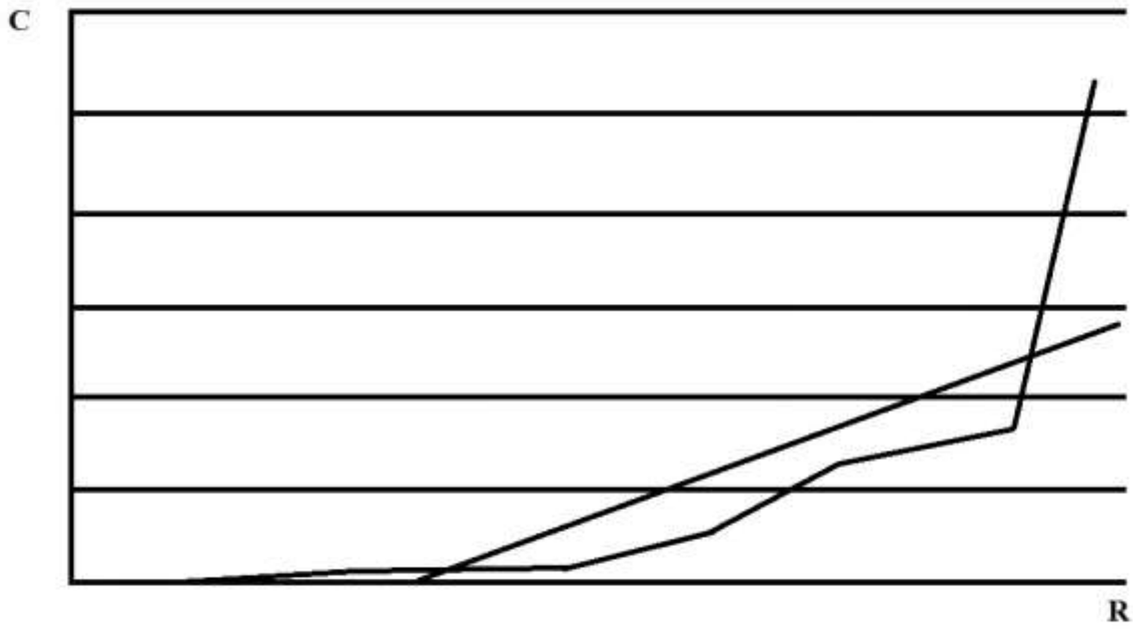
Figure 2.9 - Schedule of total costs

If the value of the probability $P_{пр} < P_{пр\,opt}$ then the costs of eliminating the consequences of aviation events will increase. If the value of the probability $P_{пр} > P_{пр\,opt}$ then the costs of developing preventive measures will grow, while the growth can be large with low efficiency of measures. Therefore, it is advisable to take into account the basic principle of investment.



C is the total cost of the SMS; Cost is the cost of activities that reduce the risk of aviation events.

Figure 2.10 - Graph of the dependence of the total costs on the funds invested in measures to reduce the risks of aviation events



C is the total cost of the SMS;

R is the risk of aviation events.

Figure 2.11 - Graph of dependence of total costs on the size of the risk of aviation events

A mathematical model of total costs can be written taking into account the classifiers of events. If we consider four types of aviation events: catastrophes, accidents, serious incidents and incidents, the mathematical model of the total costs with discrete input data will take the form:

$$\text{C}_{gen} = R' + K$$

$$= \sum_{q=1}^{v} T_q \left[\left[\left[\sum_{\alpha=1}^{\mu} \lambda_{qK_\alpha} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha a}} \cdot P(\Phi_{\text{Ка}}/\text{К}_\alpha)\right]\right.\right.$$

$$+ \left[\sum_{\alpha'=1}^{\chi} \lambda_{qK_{\alpha'}} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha' a}} \cdot P(\Phi_{\text{Ка}}/\text{К}_{\alpha'})\right]$$

$$+ \left.\left[\sum_{\alpha\prime''=1}^{\psi} \lambda_{qK_{\alpha''}} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha'' a}} \cdot P(\Phi_{\text{Ка}}/\text{К}_{\alpha''})\right]\right] \cdot \left[1 - \prod_{X=1}^{Z} P(M_{KX}/\Phi_{\text{Ка}}\right]$$

$$+ \left[\left[\sum_{\beta=1}^{\delta} \lambda_{qK_\beta} \sum_{b=1}^{n} \overline{\text{C}_{q\beta b}} \cdot P(\Phi_{Ab}/A_\beta)\right]\right.$$

$$+ \left[\sum_{\beta'=1}^{\varepsilon} \lambda_{qK_{\beta'}} \sum_{b=1}^{n} \overline{\text{C}_{q\beta' b}} \cdot P(\Phi_{Ab}/A_{\beta'})\right]$$

$$+ \left.\left[\sum_{\beta''=1}^{\eta} \lambda_{qK_{\beta''}} \sum_{b=1}^{n} \overline{\text{C}_{q\beta'' b}} \cdot P(\Phi_{Ab}/A_{\beta''})\right]\right] \cdot \left[1 - \prod_{D=1}^{H} P(M_{AD}/\Phi_{Ab}\right]$$

$$+ \left[\left[\sum_{\Upsilon=1}^{\sigma} \lambda_{qS_\Upsilon} \sum_{g=1}^{n} \overline{\text{C}_{q\Upsilon g}} \cdot P(\Phi_{Sg}/S_\Upsilon)\right]\right.$$

$$+ \left[\sum_{\Upsilon'=1}^{\tau} \lambda_{qS_{\Upsilon'}} \sum_{g=1}^{n} \overline{\text{C}_{q\Upsilon' g}} \cdot P(\Phi_{Sg}/S_{\Upsilon'})\right]$$

$$+ \left.\left[\sum_{\Upsilon''=1}^{\omega} \lambda_{qS_{\Upsilon''}} \sum_{g=1}^{n} \overline{\text{C}_{q\Upsilon'' g}} \cdot P(\Phi_{Sg}/S_{\Upsilon''})\right]\right] \cdot \left[1 - \prod_{J=1}^{T} P(M_{SJ}/\Phi_{Sg}\right]$$

$$+ \left[\left[\sum_{\varphi=1}^{\nu} \lambda_{qI_\varphi} \sum_{k=1}^{f} \overline{\text{C}_{q\varphi k}} \cdot P(\Phi_{Ik}/I_\varphi)\right]\right.$$

$$+\left[\sum_{\varphi\prime=1}^{o}\lambda_{qI_{\varphi\prime}}\sum_{k=1}^{f}\overline{C_{q\varphi\prime k}}\cdot P(\Phi_{Ik}/I_{\varphi\prime})\right]$$

$$\left.+\left[\sum_{\varphi"=1}^{\theta}\lambda_{qI_{\varphi"}}\sum_{k=1}^{f}\overline{C_{q\varphi"k}}\cdot P(\Phi_{Ik}/I_{\varphi"})\right]\right]\cdot\left[1-\prod_{R=1}^{W}P(M_{IR}/\Phi_{Ik}\right]\Bigg]$$

$$-\sum_{X=1}^{Z}\sum_{a=1}^{m}C_{0Xa}\ln\left(1-P\left(\frac{M_{KX}}{\Phi_{Ka}}\right)\right)-\sum_{D=1}^{H}\sum_{b=1}^{n}C_{0Db}\,ln\left(1-P\left(\frac{M_{AD}}{\Phi_{Ab}}\right)\right)$$

$$-\sum_{J=1}^{T}\sum_{g=1}^{l}C_{0Jg}\,ln\left(1-P\left(\frac{M_{SJ}}{\Phi_{Sg}}\right)\right)-\sum_{R=1}^{W}\sum_{k=1}^{f}C_{0Rk}\,ln\left(1-P\left(\frac{M_{IR}}{\Phi_{Ik}}\right)\right)$$

(2.28)

$K_\alpha -$ catastrophe due to technical disaster, $\alpha = \overline{1,\mu}$;

$K_{\alpha\prime} -$ catastrophe due to human error, $\alpha' = \overline{1,\chi}$;

$K_{\alpha"}$ – environmental catastrophe, $\alpha" = \overline{1,\psi}$;

A_β- - technical accident, $\beta = \overline{1,\delta}$; $A_{\beta\prime}$ - accident due to human error, $\beta' = \overline{1,\varepsilon}$; $A_{\beta"}$ - environmental accident, $\beta" = \overline{1,\eta}$;

S_Υ - serious technical incident, $\Upsilon = \overline{1,\sigma}$; $S_{\Upsilon\prime}$ - serious incident due to human factors, $\Upsilon' = \overline{1,\tau}$; $S_{\Upsilon"}$ - serious incident due to environmental impact, $\Upsilon" = \overline{1,\omega}$;

I_φ - technical incident, $\varphi = \overline{1,\nu}$; $I_{\varphi\prime}$ - incident due to human error, $\varphi' = \overline{1,o}$; $I_{\varphi"}$ - environmental incident, $\varphi" = \overline{1,\theta}$;

$\lambda_{q_{1_\varphi}}$ - intensity of incidents due to technical reasons per flights q,

$\varphi = \overline{1,v}$; $\lambda_{q_{1_{\varphi'}}}$ - the intensity of the flow of incidents due to human factor per flights q, $\varphi' = \overline{1,o}$; $\lambda_{q_{1_{\varphi''}}}$ - intensity of incidents due to environmental impact per flights q, $\varphi'' = \overline{1,\theta}$;

$\lambda_{q_{K_\alpha}}$ - the intensity of the flow of catastrophes due to technical reasons per flights q;

$\lambda_{q_{K_{\alpha'}}}$ - the intensity of the flow of catastrophes due to the human factor per flights q;

$\lambda_{q_{K_{\alpha''}}}$ — the intensity of the flow of catastrophes due to impact the environment per flights q;

$\lambda_{q_{A_\beta}}$ - accident flow rate due to technical reasons per flights q;

$\lambda_{q_{A_{\beta'}}}$ - the intensity of the accident flow due to the human factor per flights q;

$\lambda_{q_{A_{\beta''}}}$ - intensity of incidents due to environmental impact per flights q;

$\lambda_{q_{S_\Upsilon}}$ — the intensity of the flow of serious incidents due to technical reasons per flights q;

$\lambda_{q_{S_{\Upsilon'}}}$ — the intensity of the flow of serious incidents due to the human factor per flights q;

$\lambda_{q_{S_{\Upsilon''}}}$ — the intensity of the flow of serious incidents due to environmental impact per flights q;

$P(\Phi_{Ka}/K_\alpha)$ - K_α for technical reasons, $a = \overline{1,m}$; $\alpha = \overline{1,\mu}$; $P(\Phi_{Ka}/K_{\alpha'})$ - conditional probability of event occurrence K_α, due to human factors, $a = \overline{1,m}$;

$\alpha' = \overline{1,\chi}$; P($\Phi_{Ka}$/$K_{\alpha"}$) - conditional probability of event occurrence $K_{\alpha"}$ due to environmental influences, a = $\overline{1,m}$; $\alpha" = \overline{1,\psi}$;

P(Φ_{Ab}/A_{β}) - conditional probability of event occurrence A_{β} for technical reasons, $b = \overline{1,n}$; $\beta = \overline{1,\delta}$; P($\Phi_{Ab}/A_{\beta'}$) - conditional probability of event occurrence $A_{\beta'}$, due to human factors, $b = \overline{1,n}$; $\beta' = \overline{1,\varepsilon}$; P($\Phi_{Ab}/A_{\beta"}$) - conditional probability of event occurrence $A_{\beta"}$ due to environmental influences, $b = \overline{1,n}$; $\beta" = \overline{1,\eta}$;

P(Φ_{Ik}/I_{φ}) - conditional probability of event occurrence I_{φ}, for technical reasons, $k = \overline{1,f}$; $\varphi = \overline{1,v}$; P($\Phi_{Ik}/I_{\varphi'}$) - conditional probability of event occurrence $I_{\varphi'}$ due to human factors, $k = \overline{1,f}$; $\varphi' = \overline{1,o}$; P($\Phi_{Ik}/I_{\varphi"}$) conditional probability of event occurrence $I_{\varphi"}$ due to environmental influences, $k = \overline{1,f}$; $\varphi" = \overline{1,\theta}$;

P(Φ_{Sg}/S_{Υ}) - conditional probability of event occurrence S_{Υ} for technical reasons, $g = \overline{1,l}$; $\Upsilon = \overline{1,\sigma}$; P($\Phi_{Sg}/S_{\Upsilon'}$) - conditional probability of event occurrence S_{Υ}, due to human factors, $g = \overline{1,l}$; $\Upsilon' = \overline{1,\tau}$; P($\Phi_{Sg}/S_{\Upsilon"}$) conditional probability of event occurrence $S_{\Upsilon"}$ - due to environmental influences, $g = \overline{1,l}$; $\Upsilon' = \overline{1,\omega}$;

$\overline{C_{q\alpha a}}$ - average catastrophe damage due to technical reasons per flights q, $a = \overline{1,m}$;

$\alpha = \overline{1,\mu}$; $\overline{C_{q\alpha' a}}$— average catastrophe damage due to human factors per flights q, $a = \overline{1,m}$; $\alpha' = \overline{1,\chi}$; $\overline{C_{q\alpha" a}}$ - average catastrophe damage due to environmental impact per flights q, $a = \overline{1,m}$; $\alpha" = \overline{1,\psi}$;

$\overline{C_{q\beta b}}$ - average damage caused by an accident due to technical reasons per flights q, $b = \overline{1,n}$; $\beta = \overline{1,b}$; $\overline{C_{q\beta\prime b}}$ - average accident damage due to human factors per flights q, $b = \overline{1,n}$; $\beta' = \overline{1,\varepsilon}$; $\overline{C_{q\beta"b}}$ - average damage caused by the accident due to environmental impact per flights q, $= \overline{1,n}$; $\beta" = \overline{1,\eta}$;

$\overline{C_{q\Upsilon g}}$ - the average damage of a serious incident due to a technical reason per flights $g = \overline{1,l}$; $\Upsilon = \overline{1,\sigma}$; $\overline{C_{q\Upsilon\prime g}}$ - the average damage caused by a serious incident human factor per flights q, $g = \overline{1,l}$; $\Upsilon' = \overline{1,\tau}$; $\overline{C_{q\Upsilon"g}}$ - average damage caused by a serious incident due to environmental impact per flights q, $g = \overline{1,l}$; $\Upsilon" = \overline{1,\omega}$;

$\overline{C_{q\varphi k}}$ - average damage caused by the incident due to technical reasons per flights q, $k = \overline{1,f}$; $\varphi = \overline{1,v}$; $\overline{C_{q\varphi\prime k}}$ - average damage caused by the incident due to human factors per flights q, $k = \overline{1,f}$; $\varphi' = \overline{1,o}$; $\overline{C_{q\varphi"k}}$ - average incident damage due to environmental impact per flights q; $k = \overline{1,f}$; $\varphi" = \overline{1,\theta}$;

P($M_{\text{К}X}/A_{Ka}$)— catastrophe prevention probability;

P(M_{AD}/A_{Ab})— accident prevention probability;

P(M_{SJ}/A_{Sg})— serious incident prevention probability;

P(M_{IR}/A_{Ik})— incident prevention probability;

C_{0Xa}, C_{0Db}, C_{0Jg}, C_{0Rk} – the constant of process of leveling up P($M_{\text{КХ}}/\Phi_{\text{Ка}}$), P($M_{AD}/A_{Ab}$), P($M_{SJ}/A_{Sg}$), P($M_{IR}/A_{Ik}$) respectively.

In case of continuous distribution of damage:

$$C_{total}=\sum_{q=1}^{v} T_q \left[\left[\sum_{\alpha=1}^{\mu} \lambda_{qK_\alpha} \int_{C_{q\alpha a\,1}}^{C_{q\alpha a\,2}} P(\Phi_{\text{Ка}}/\text{К}_\alpha) d\overline{C_{q\alpha a}} + \sum_{\alpha'=1}^{\chi} \lambda_{qK_{\alpha'}} \int_{C_{q\alpha' a\,1}}^{C_{q\alpha' a\,2}} P(\Phi_{\text{Ка}}/\text{К}_{\alpha'}) d\overline{C_{q\alpha' a}} + \sum_{\alpha"=1}^{\psi} \lambda_{qK_{\alpha"}} \int_{C_{q\alpha" a\,1}}^{C_{q\alpha" a\,2}} P(\Phi_{\text{Ка}}/\text{К}_{\alpha"}) d\overline{C_{q\alpha" a}}\right] \cdot [1 -$$

$$\prod_{X=1}^{Z} P(M_{KX}/\Phi_{\text{Ka}})] + \Big[\sum_{\beta=1}^{\delta} \lambda_{q\text{A}_\beta} \int_{C_{q\beta b\,1}}^{C_{q\beta b\,2}} P(\Phi_{Ab}\,/A_\beta) d\overline{C_{q\beta b}} +$$

$$\sum_{\beta'=1}^{\varepsilon} \lambda_{q\text{A}_{\beta'}} \int_{C_{q\beta' b\,1}}^{C_{q\beta' b\,2}} P(\Phi_{Ab}\,/A_{\beta'}) d\overline{C_{q\beta' b}} + \sum_{\beta"=1}^{\eta} \lambda_{q\text{A}_{\beta"}} \int_{C_{q\beta" b\,1}}^{C_{q\beta" b\,2}} P(\Phi_{Ab}\,/A_{\beta"}) d\overline{C_{q\beta" b}}\Big] \cdot$$

$$[1 - \prod_{D=1}^{H} P(M_{AD}/\Phi_{Ab})] + \Big[\sum_{\Upsilon'=1}^{\sigma} \lambda_{qS\Upsilon} \int_{C_{c\Upsilon g\,1}}^{C_{c\Upsilon g\,2}} P(\Phi_{Sg}\,/S_\Upsilon) d\overline{C_{q\Upsilon g}} +$$

$$\sum_{\Upsilon=1}^{\tau} \lambda_{qS\Upsilon'} \int_{C_{c\Upsilon' g\,1}}^{C_{c\Upsilon' g\,2}} P(\Phi_{Sg}\,/S_{\Upsilon'}) d\overline{C_{q\Upsilon' g}} + \sum_{\Upsilon"=1}^{\omega} \lambda_{qS\Upsilon"} \int_{C_{c\Upsilon" g\,1}}^{C_{c\Upsilon" g\,2}} P(\Phi_{Sg}\,/S_{\Upsilon"}) d\overline{C_{q\Upsilon" g}}\Big] \cdot$$

$$\left[1 - \prod_{J=1}^{T} P\left(M_{SJ}/\Phi_{Sg}\right)\right] + \Big[\sum_{\varphi=1}^{v} \lambda_{qI\varphi} \int_{C_{q\varphi k\,1}}^{C_{q\varphi k\,2}} P(\Phi_{Ik}\,/I_\varphi) d\overline{C_{q\varphi k}} +$$

$$\sum_{\varphi'=1}^{o} \lambda_{qI\varphi'} \int_{C_{q\varphi' k\,1}}^{C_{q\varphi' k\,2}} P(\Phi_{Ik}\,/I_{\varphi'}) d\overline{C_{q\varphi' k}} + \sum_{\varphi"=1}^{\omega} \lambda_{qI\varphi"} \int_{C_{q\varphi" k\,1}}^{C_{q\varphi" k\,2}} P(\Phi_{Ik}\,/I_{\varphi"}) d\overline{C_{q\varphi" k}}\Big] \cdot$$

$$\Big[1 - \prod_{R=1}^{W} P(M_{IR}/\Phi_{Ik})]\Big] - \sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa} \ln(1 -$$

$$P(M_{KX}/\Phi_{\text{Ka}})) - \sum_{D=1}^{H}\sum_{b=1}^{n} C_{0Db} \ln\left(1 - P\left(M_{AD}/\Phi_{Ab}\right)\right) - \sum_{J=1}^{T}\sum_{g=1}^{l} C_{0Jg} \ln(1 -$$

$$P(M_{SJ}/\Phi_{Sg})) - \sum_{R=1}^{W}\sum_{k=1}^{f} C_{0Rk} \ln\left(1 - P\left(M_{IR}/\Phi_{Ik}\right)\right)$$

(2.29)

Formulas (9), (10) can be investigated for extremum as a function of several real variables with respect to $P(M_{KX}/\Phi_{\text{Ka}})$, $P\left(M_{AD}/\Phi_{Ab}\right)$, $P(M_{SJ}/\Phi_{Sg})$, $P\left(M_{IR}/\Phi_{Ik}\right)$. For example, in the case of discrete raw data:

$$\frac{\partial(R'+K)}{\partial P(M_{KX}/\Phi_{\text{Ka}})}; \frac{\partial(R'+K)}{\partial P\left(M_{AD}/\Phi_{Ab}\right)}; \frac{\partial(R'+K)}{\partial P(M_{SJ}/\Phi_{Sg})}; \frac{\partial(R'+K)}{\partial P\left(M_{IR}/\Phi_{Ik}\right)};$$

(2.30)

$$\frac{\partial(R'+K)}{\partial P\left(M_{KX}/\Phi_{\Phi\text{a}}\right)} = -\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\alpha=1}^{\mu} \lambda_{qK_\alpha} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha a}} \cdot P(\Phi_{\text{Ka}}/\text{K}_\alpha)\right] + \\ \left[\sum_{\alpha'=1}^{\chi} \lambda_{qK_{\alpha'}} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha' a}} \cdot P(\Phi_{\text{Ka}}/\text{K}_{\alpha'})\right] + \\ \left[\sum_{\alpha''=1}^{\psi} \lambda_{qK_{\alpha''}} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha'' a}} \cdot P(\Phi_{\text{Ka}}/\text{K}_{\alpha''})\right] \end{array}\right] + \sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa} \frac{1}{1-P\left(\frac{M_{KX}}{\Phi_{\text{KA}}}\right)} = 0$$

(2.31)

$$P(M_{KX}/\Phi_{Ka})_{opt} = 1 - \frac{\sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa}}{\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\alpha=1}^{\mu} \lambda_{qK_\alpha} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha a}} \cdot P(\Phi_{\text{Ka}}/\text{K}_\alpha)\right] + \\ \left[\sum_{\alpha'=1}^{\chi} \lambda_{qK_{\alpha'}} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha' a}} \cdot P(\Phi_{\text{Ka}}/\text{K}_{\alpha'})\right] + \\ \left[\sum_{\alpha''=1}^{\psi} \lambda_{qK_{\alpha''}} \sum_{a=1}^{m} \overline{\text{C}_{q\alpha'' a}} \cdot P(\Phi_{\text{Ka}}/\text{K}_{\alpha''})\right] \end{array}\right]}$$

(2.32)

Same for $\left(M_{AD}/\Phi_{Ab}\right)$, $P(M_{SJ}/\Phi_{Sg})$, $P\left(M_{IR}/\Phi_{Ik}\right)$:

$$\frac{\partial(R'+K)}{\partial P\left(M_{AD}/\Phi_{Ab}\right)} = -\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\beta=1}^{\delta} \lambda_{qK_\beta} \sum_{b=1}^{n} \overline{\mathrm{C}_{q\beta b}} \cdot P(\Phi_{Ab}/A_\beta)\right] + \\ \left[\sum_{\beta'=1}^{\varepsilon} \lambda_{qK_{\beta'}} \sum_{b=1}^{n} \overline{\mathrm{C}_{q\beta' b}} \cdot P(\Phi_{Ab}/A_{\beta'})\right] + \\ \left[\sum_{\beta''=1}^{\eta} \lambda_{qK_{\beta''}} \sum_{b=1}^{n} \overline{\mathrm{C}_{q\beta'' b}} \cdot P(\Phi_{Ab}/A_{\beta''})\right] \end{array} \right] + \sum_{D=1}^{H}\sum_{b=1}^{n} C_{0Db} \frac{1}{1-P\left(\frac{M_{AD}}{\Phi_{Ab}}\right)} = 0$$

(2.33)

$$\frac{\partial(R'+K)}{\partial P\left(M_{SJ}/\Phi_{Sg}\right)} = -\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\Upsilon=1}^{\sigma} \lambda_{qS_\Upsilon} \sum_{g=1}^{n} \overline{\mathrm{C}_{q\Upsilon g}} \cdot P(\Phi_{Sg}/S_\Upsilon)\right] + \\ \left[\sum_{\Upsilon=1}^{\tau} \lambda_{qS_{\Upsilon'}} \sum_{g=1}^{n} \overline{\mathrm{C}_{q\Upsilon' g}} \cdot P(\Phi_{Sg}/S_{\Upsilon'})\right] + \\ \left[\sum_{\Upsilon''=1}^{\omega} \lambda_{qS_{\Upsilon''}} \sum_{g=1}^{n} \overline{\mathrm{C}_{q\Upsilon'' g}} \cdot P(\Phi_{Sg}/S_{\Upsilon''})\right] \end{array} \right] + \sum_{J=1}^{T}\sum_{g=1}^{l} C_{0Jg} \frac{1}{1-P\left(\frac{M_{SJ}}{\Phi_{Sg}}\right)} = 0$$

(2.34)

$$\frac{\partial(R'+K)}{\partial P\left(M_{IR}/\Phi_{Ik}\right)} = -\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\varphi=1}^{\nu} \lambda_{qI_{\varphi}} \sum_{k=1}^{f} \overline{\mathrm{C}_{q\varphi k}} \cdot P(\Phi_{Ik}/I_{\varphi})\right] + \\ \left[\sum_{\varphi'=1}^{o} \lambda_{qI_{\varphi'}} \sum_{k=1}^{f} \overline{\mathrm{C}_{q\varphi' k}} \cdot P(\Phi_{Ik}/I_{\varphi'})\right] + \\ \left[\sum_{\varphi"=1}^{\theta} \lambda_{qI_{\varphi"}} \sum_{k=1}^{f} \overline{\mathrm{C}_{q\varphi" k}} \cdot P(\Phi_{Ik}/I_{\varphi"})\right] \end{array}\right] + \sum_{R=1}^{W}\sum_{k=1}^{f} C_{0Rk} \frac{1}{1-P\left(\frac{M_{IR}}{\Phi_{Ik}}\right)} = 0$$

(2.35)

The extremum of the total cost formula is determined by the values:

$$P(M_{AD}/\Phi_{Ab}) = 1 - \frac{\sum_{D=1}^{H}\sum_{b=1}^{n} C_{0Db}}{\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\beta=1}^{\delta} \lambda_{qK_{\beta}} \sum_{b=1}^{n} \overline{\mathrm{C}_{q\beta b}} \cdot P(\Phi_{Ab}/A_{\beta})\right] + \\ \left[\sum_{\beta'=1}^{\varepsilon} \lambda_{qK_{\beta'}} \sum_{b=1}^{n} \overline{\mathrm{C}_{q\beta' b}} \cdot P(\Phi_{Ab}/A_{\beta'})\right] + \\ \left[\sum_{\beta"=1}^{\eta} \lambda_{qK_{\beta"}} \sum_{b=1}^{n} \overline{\mathrm{C}_{q\beta" b}} \cdot P(\Phi_{Ab}/A_{\beta"})\right] \end{array}\right]}$$

(2.36)

$$P(M_{SJ}/\Phi_{Sg}) = 1 - \frac{\sum_{J=1}^{T}\sum_{g=1}^{l} C_{0Jg}}{\sum_{q=1}^{v} T_q \left[\begin{array}{c} \left[\sum_{\Upsilon=1}^{\sigma} \lambda_{qS_{\Upsilon}} \sum_{g=1}^{n} \overline{\mathrm{C}_{q\Upsilon g}} \cdot P(\Phi_{Sg}/S_{\Upsilon})\right] + \\ \left[\sum_{\Upsilon'=1}^{\tau} \lambda_{qS_{\Upsilon'}} \sum_{g=1}^{n} \overline{\mathrm{C}_{q\Upsilon' g}} \cdot P(\Phi_{Sg}/S_{\Upsilon'})\right] + \\ \left[\sum_{\Upsilon"=1}^{\omega} \lambda_{qS_{\Upsilon"}} \sum_{g=1}^{n} \overline{\mathrm{C}_{q\Upsilon" g}} \cdot P(\Phi_{Sg}/S_{\Upsilon"})\right] \end{array}\right]}$$

(2.37)

$$P\left(M_{IR}/\Phi_{Ik}\right)1 = 1 - \frac{\sum_{R=1}^{W}\sum_{k=1}^{f} C_{0Rk}}{\sum_{q=1}^{v} T_q \begin{bmatrix} \left[\sum_{\varphi=1}^{\nu} \lambda_{qI_\varphi} \sum_{k=1}^{f} \overline{C_{q\varphi k}} \cdot P(\Phi_{Ik}/I_\varphi)\right] + \\ \left[\sum_{\varphi'=1}^{o} \lambda_{qI_{\varphi'}} \sum_{k=1}^{f} \overline{C_{q\varphi' k}} \cdot P(\Phi_{Ik}/I_{\varphi'})\right] + \\ \left[\sum_{\varphi"=1}^{\theta} \lambda_{qI_{\varphi"}} \sum_{k=1}^{f} \overline{C_{q\varphi" k}} \cdot P(\Phi_{Ik}/I_{\varphi"})\right] \end{bmatrix}}$$

(2.38)

Using the Hesse matrix, the type of extremum is determined:

$$f"(x) =$$

$$\begin{matrix} \frac{\partial^2(R'+K)}{\partial^2 P(M_{KX}/\Phi_{\text{Ka}})} & \frac{\partial^2(R'+K)}{\partial P(M_{KX}/\Phi_{\text{Ka}})\partial P\left(M_{AD}/\Phi_{Ab}\right)} & \frac{\partial^2(R'+K)}{\partial P(M_{KX}/\Phi_{\text{Ka}})\partial P(M_{SJ}/\Phi_{Sg})} & \frac{\partial^2(R'+K)}{\partial P(M_{KX}/\Phi_{\text{Ka}})\partial P\left(M_{IR}/\Phi_{Ik}\right)} \\ \frac{\partial^2(R'+K)}{\partial P(M_{AD}/\Phi_{Ab})\partial P\left(M_{\text{KX}}/\Phi_{Ka}\right)} & \frac{\partial^2(R'+K)}{\partial^2 P(M_{AD}/\Phi_{Ab})} & \frac{\partial^2(R'+K)}{\partial P(M_{AD}/\Phi_{Ab})\partial P\left(M_{SJ}/\Phi_{Sg}\right)} & \frac{\partial^2(R'+K)}{\partial P(M_{AD}/\Phi_{Ab})\partial P\left(M_{IR}/\Phi_{Ik}\right)} \\ \frac{\partial^2(R'+K)}{\partial P(M_{SJ}/\Phi_{Sg})\partial P\left(M_{\text{KX}}/\Phi_{Ka}\right)} & \frac{\partial^2(R'+K)}{\partial P(M_{SJ}/\Phi_{Sg})\partial P\left(M_{AD}/\Phi_{Ab}\right)} & \frac{\partial^2(R'+K)}{\partial^2 P(M_{SJ}/\Phi_{Sg})} & \frac{\partial^2(R'+K)}{\partial P(M_{SJ}/\Phi_{Sg})\partial P\left(M_{IR}/\Phi_{Ik}\right)} \\ \frac{\partial^2(R'+K)}{\partial P(M_{IR}/\Phi_{Ik})\partial P\left(M_{\text{KX}}/\Phi_{Ka}\right)} & \frac{\partial^2(R'+K)}{\partial P(M_{IR}/\Phi_{Ik})\partial P\left(M_{AD}/\Phi_{Ab}\right)} & \frac{\partial^2(R'+K)}{\partial P(M_{IR}/\Phi_{Ik})\partial P\left(M_{SJ}/\Phi_{Sg}\right)} & \frac{\partial^2(R'+K)}{\partial^2 P(M_{IR}/\Phi_{Ik})} \end{matrix}$$

(2.39)

$$\frac{\partial^2(R'+K)}{\partial^2 P(M_{KX}/\Phi_{\text{Ka}})} = \sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa} \frac{1}{(1-P(M_{KX}/\Phi_{\text{Ka}}))^2}; \quad (2.40)$$

$$\frac{\partial^2(R'+K)}{\partial^2 P(M_{AD}/\Phi_{Ab})} = \sum_{D=1}^{H}\sum_{b=1}^{n} C_{0Db} \frac{1}{(1-P(M_{AD}/\Phi_{Ab}))^2}; \quad (2.41)$$

$$\frac{\partial^2(R'+K)}{\partial^2 P(M_{SJ}/\Phi_{Sg})} = \sum_{J=1}^{T}\sum_{g=1}^{l} C_{0Jg} \frac{1}{(1-P(M_{SJ}/\Phi_{Sg}))^2}; \quad (2.42)$$

$$\frac{\partial^2(R'+K)}{\partial^2 P(M_{IR}/\Phi_{Ik})} = \sum_{R=1}^{W}\sum_{k=1}^{f} C_{0Rk} \frac{1}{(1-P(M_{IR}/\Phi_{Ik}))^2}. \quad (2.43)$$

The mixed derivatives of the matrix are equal to zero, therefore, the matrix will take the following form:

$$f''(x) = \begin{vmatrix} \sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa}\frac{1}{(1-P(M_{KX}/\Phi_{Ka}))^2} & 0 & 0 & 0 \\ 0 & \sum_{D=1}^{H}\sum_{b=1}^{n} C_{0Db}\frac{1}{(1-P(M_{AD}/\Phi_{Ab}))^2} & 0 & 0 \\ 0 & 0 & \sum_{J=1}^{T}\sum_{g=1}^{l} C_{0Jg}\frac{1}{(1-P(M_{SJ}/\Phi_{Sg}))^2} & 0 \\ 0 & 0 & 0 & \sum_{R=1}^{W}\sum_{k=1}^{f} C_{0Rk}\frac{1}{(1-P(M_{IR}/\Phi_{Ik}))^2} \end{vmatrix}$$

(2.44)

>1

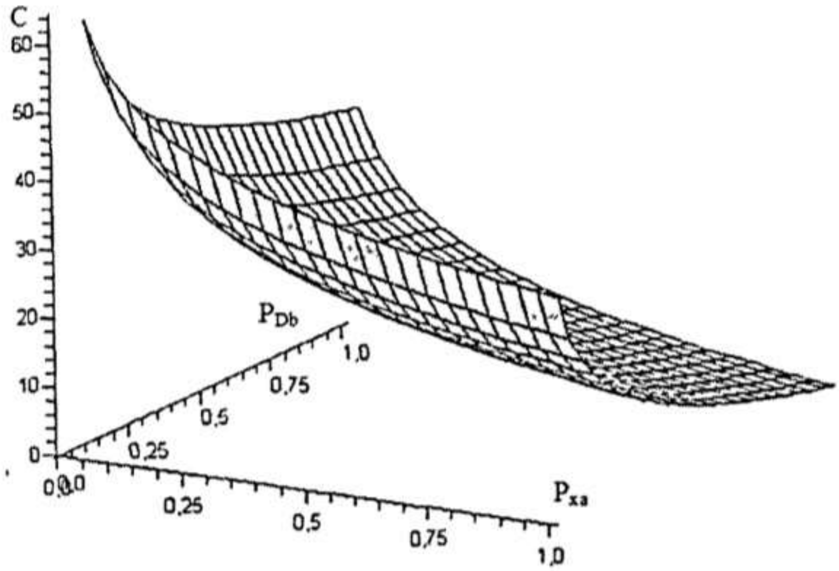
$$\sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa}\frac{1}{(1-P(M_{KX}/F_{Ka}))^2} > 0; \sum_{D=1}^{H}\sum_{b=1}^{n} C_{0Db}\frac{1}{(1-P(M_{AD}/F_{Ab}))^2} > 0\,.$$

$$\sum_{R=1}^{W}\sum_{k=1}^{f} C_{0Rk}\frac{1}{(1-P(M_{IR}/F_{Ik}))^2} > 0; \sum_{J=1}^{T}\sum_{g=1}^{l} C_{0Jg}\frac{1}{(1-P(M_{SJ}/F_{Sg}))^2} > 0\,.$$

(2.45)

Due to the fact that the diagonal terms of the determinant are positive, and all other elements are equal to zero, the determinant is always positive. In this case, the extreme is the minimum. Hence it follows that the relief (hypersurface) of the total costs is concave.

A conventional example of building a relief for two types of aviation events is shown in Figure 2.12.



C - total cumulative SMS costs;

P_{DB}- probability of preventing accidents;

P_{Xa}- probability of disaster prevention.

Figure 2.12 - Relief of total costs for two types of aviation events

The choice of the most effective event can be done using the gradient method:

$$antigrad\left\{\left(\frac{\partial^2(R'+K)}{\partial^2 P(M_{KX}/\Phi_{\text{Ka}})}\right)\overrightarrow{e_1}+\left(\frac{\partial^2(R'+K)}{\partial^2 P(M_{AD}/\Phi_{Ab})}\right)\overrightarrow{e_2}+\left(\frac{\partial^2(R'+K)}{\partial^2 P(M_{SJ}/\Phi_{Sg})}\right)\overrightarrow{e_3}+\left(\frac{\partial^2(R'+K)}{\partial^2 P(M_{IR}/\Phi_{Ik})}\right)\overrightarrow{e_4}\right\} \quad (2.46)$$

The largest projection will show the direction to the most effective event risk mitigation measure.

The use of the presented model requires processing a large amount of data and carrying out a variety of corresponding calculations of the model parameters. In this regard, on the basis of this method of calculating the optimal probability of prevention, it is necessary to develop software. The integration of such software into the airline's SMS will improve the process of managing the risk factors for the occurrence of aviation events and, thus, build a priority strategy for improving flight safety while maintaining the balance of production costs and ensuring flight safety (at minimum total costs), and in this case, maximum economic efficiency.

2.6. Optimization of the cost structure for the prevention of aviation events in the flight safety management system

Based on the optimal level of probability of preventing aviation events in order to optimize costs in SMS, it is necessary from all available ones to choose measures to reduce the risks of aviation events, based on the conditions:

- maximum reduction of the risks of aviation events;

- total costs should not exceed the minimum calculated by the method of determining the optimal probability of preventing aviation events.

This task is a linear programming task. As a constraint, the minimum total costs C_{min} are taken when the minimum risk level R is reached.

If we assume that the number of systems (production processes) in the organization S_{i0} $(i = \overline{1, m_0})$, the corresponding number of measures to reduce the risk of aviation events that will be implemented in the organization's systems is M_{i0}, the corresponding total costs for each event - C_{i0}, then the mathematical formulation of this problem will look like:

$$\begin{cases} R \to min \\ \sum_{i_0=1}^{m_0} C_{i0} \leq C_{min} \\ C_{min} > 0 \end{cases} \qquad (2.47)$$

The solution to problem (I) can be found using a standard linear programming package.

As a result of solving such a problem, an optimal list of measures will be determined, which will ensure an increase in flight safety at minimal total costs.

2.7. Conclusions on chapter 2

1. The developed mathematical model of total costs makes it possible to determine the target level of improving flight safety at minimum total costs.

2. The study of the total cost hypersurface in SMS using the Hessian matrix showed that the cost surface is concave, therefore, the method for determining the optimal probability of preventing aviation events during the operation of air transport is correct.

3. The developed method for calculating the optimal probability of preventing aviation events provides for the formation of a list of measures to reduce the risks of aviation events from the database with minimal total costs corresponding to the optimal probability of preventing aviation events, which is important in the process of managing risk factors.

4. The resulting risk formula for the implementation of aviation events takes into account all types of events, the intensity of the flow of events, damage, the likelihood of preventing aviation events, which makes it possible to identify the effectiveness of measures to reduce the level of risks of events for the entire fleet of aircraft.

5. The revealed dependence of financial costs for the implementation of measures that reduce risks on the probability of preventing aviation events allows us to determine the effectiveness of funds invested in measures to improve flight safety on the principle of maximum investment efficiency.

6. Due to the fact that the calculations of the optimal probability of preventing aviation events and the formation on its basis of a set of measures with minimal total costs is more convenient to carry out in an automated mode, it is advisable to develop appropriate software.

CHAPTER 3. DEVELOPMENT OF THE SOFTWARE FOR CALCULATION OF THE OPTIMUM PROBABILITY OF AVIATION EVENTS PREVENTION

3.1. Conceptual problem statement

The input data for calculating the optimal probability of preventing aviation events are: the type of aircraft, the list of factors of aviation events, the name of risk mitigation measures, their cost, the amount of expected damage from aviation events, aircraft raid, and the intensity of flows of aviation events.

The software should be based on the formulas developed in Chapter 2.

Having received the initial data, the program should:

1. Calculate the probability of preventing aviation events P_{pr}, of all measures aimed at reducing the risks of aviation events;

2. Calculate the optimal probability of preventing aviation events $P_{pr\ \ opt}$, initial total costs C_{total}, minimum total * costs C_{min}, corresponding to the optimal probability of preventing aviation events $P_{pr\ \ opt}$.

3. Form a list of measures to reduce the risk of aviation events, the adoption of which ensures the minimum total costs and the greatest reduction of risks.

3. Form a list of measures to reduce the risk of aviation events, the adoption of which ensures the minimum total costs and the greatest reduction of risks.

The output will be displayed in the form of a report, which will contain the information necessary to make a decision on managing risk factors based on the criterion of minimum total costs.

3.2. The main stages of software development

During the development of software, the following stages must be performed: formation of the goal and primary requirements for software, design of software architecture (structure), prototyping, specification of requirements.

The objectives and primary requirements for the software are outlined in Section 3.1 of Chapter 3.

Based on the formulated software requirements, the choice of software is carried out to effectively achieve the goal. This stage is called design.

After the completion of the design phase, a primary image (prototype) of the software is formed to test the fundamental possibility of achieving the goal using the selected software.

After the approval of the prototype, there is a stage of detailed requirements and software idea revision.

The testing phase is carried out using a control calculation. If there is a control set of input parameters and the required data, a comparison is made between the results of the control calculation and the results obtained by calculating the software. A mismatch in the results indicates a computational error in the software. In this case, the calculations are investigated for discrepancies in the calculations. Control calculations include all possible options for both standard calculations and calculations with different boundary conditions (in the presence of boundary or unacceptable parameter values, conflicting values of various parameters, in the absence of certain parameters).

3.3. Technologies to be used

To build the software, a group of Microsoft software can be chosen, which makes it possible to implement the required functionality with the least loss in time and use a huge basis of modern auxiliary software for building.

3.3.1. Software architecture

The development of the program can be carried out in the key of a three-tier architecture, in which the parts of data storage (database management system), information processing (server) and user interaction (client part) are separated.

3.3.1.1. Data storage structure

For data storage, a relational database management system Microsoft SQL Server 2012 can be chosen in the Express edition free for use both for personal and commercial purposes.

Microsoft SQL Server 2012 is a powerful free data management system that provides robust and reliable data storage for websites and desktop applications.

The database structure is a set of entities or objects from the real world, both physical (aircraft) and logical (type of factor influencing the occurrence of an aviation event, the probability of aviation events, the probability of preventing aviation events, the intensity and expected damage of aviation events) (Table 3.1). Each entity has a set of attributes that distinguish instances of these entities from each other. Entities in the database are represented by tables, their attributes are fields (columns) of tables. Relationships are technically fields that contain the identifiers of the elements to which they refer.

Table 3.1- Description of the database elements of the program for calculating the optimal probability of preventing aviation events

Element code	Item Description (Type)
1	2
PlaneGroups	groups (types) of aircraft
Id	unique identifier (numeric)
Name	name (string)
Planes	List of aircraft
Id	unique identifier (numeric)
Name	name (string)
PlaneGroup	reference (relation) to a group of aircraft
FactorTypes	Types of factors
Id	unique identifier (numeric)

Name	name (string)
Factors	List of factors
Id	unique identifier (numeric)
Name	name (string)
Factorype	reference (relation) to the type of factor
EventTypes	Types of aviation events
Id	unique identifier (numeric)
Name	name (string)
Events	List of aviation events
Id	unique identifier (numeric)
EventType	reference (relation) to the type of aviation event
PlaneGroup	reference (relation) to a group of aircraft
Plane	reference (relation) to a specific aircraft
Expense	costs (monetary)
FlyTime	flight time (numeric)
Rate	event rate (numeric)
EventFactors	Factors influencing aviation events
Id	unique identifier (numeric)
Event	reference (relation) to a specific aviation event
FactorType	reference (relation) to the type of factor
Factor	Reference (relation) to a factor
Solves	List of solutions
Id	unique identifier (numeric)
Name	name (string)
PreventActionTypes	A set of prevention measures for a specific solution
Id	unique identifier (numeric)
Solve	reference (attitude) to a specific solution
PreventActionType	reference (relation) to the type of prevention measure
EventType	reference (relation) to the type of aviation event

FactorType	reference (relation) to the type of factor
Factor	Reference (relation) to a factor
PlaneGroup	reference (relation) to a group of aircraft
Plane	Link (relation) to a specific aircraft
Cost	cost of the event (monetary)
PreventCount	number of events prevented (numeric)
OccuredCount	number of events unprevented (numeric)

Figure 3.1 shows a block diagram of the structure that displays all the entities used in the system to store the required information.

The database management system has a set of developer tools convenient for development: SQL Server Management Studio, with which it is possible to perform functions of figuring, managing and administering all database components, Microsoft Visual Studio Light Swith - for database development.

3.3.1.2. Client part of the program

To build the client (user) part, Silverlight technology can be chosen, which allows you to create beautiful and convenient user interfaces.

Silverlight is a browser plugin for displaying animation and text on the screen.

The client side of the application can be launched in different modes:

1. Directly on the user's computer as a separate executable Windows application;

2. In the user's Internet browser (modern browsers Internet Explorer 8,9,10, Google Chrome, Mozilla Firefox, Apple Safari are available) on various operating systems (Windows, Mac OS, Linux), which allows the user to connect and start using applications without complex manipulations with its configuration and installation (on some operating systems it may be necessary to simply install the Silverlight plugin).

The development of the client side can be carried out using the technology for building applications Microsoft Visual Studio LightSwitch 2011, which reduces the time spent on writing infrastructure code and allows you to focus on the main task.

Microsoft Visual Studio Lights witch 2011 is a tool that allows you to quickly create and deploy programs.

The client part should contain the ability to connect to a remote or local database through the server component, change data in the database management system and perform calculations based on the completed solution options.

The client module should have a set of visual elements that are designed to fully customize the data used in the calculation. They will be accessed in two modes: administrator mode and operator mode.

Administrator mode will imply editing of the main setting elements, such as:

- the list of event types,
- a list of factors,
- aircraft list,
- list of types of events.

Operator mode is the execution of calculations and setting the main calculation elements: the list of events; list of calculations; obtaining results.

3.4. Calculating software

All mathematical calculations will be implemented on the side of the database management system, which provides the system with both the ability to easily access existing calculations, and to fill in data and perform new calculations based on existing systems. A flowchart of optimization of the process of managing risk factors of aviation events based on the criterion of minimum total costs is shown in Figure 3.10.

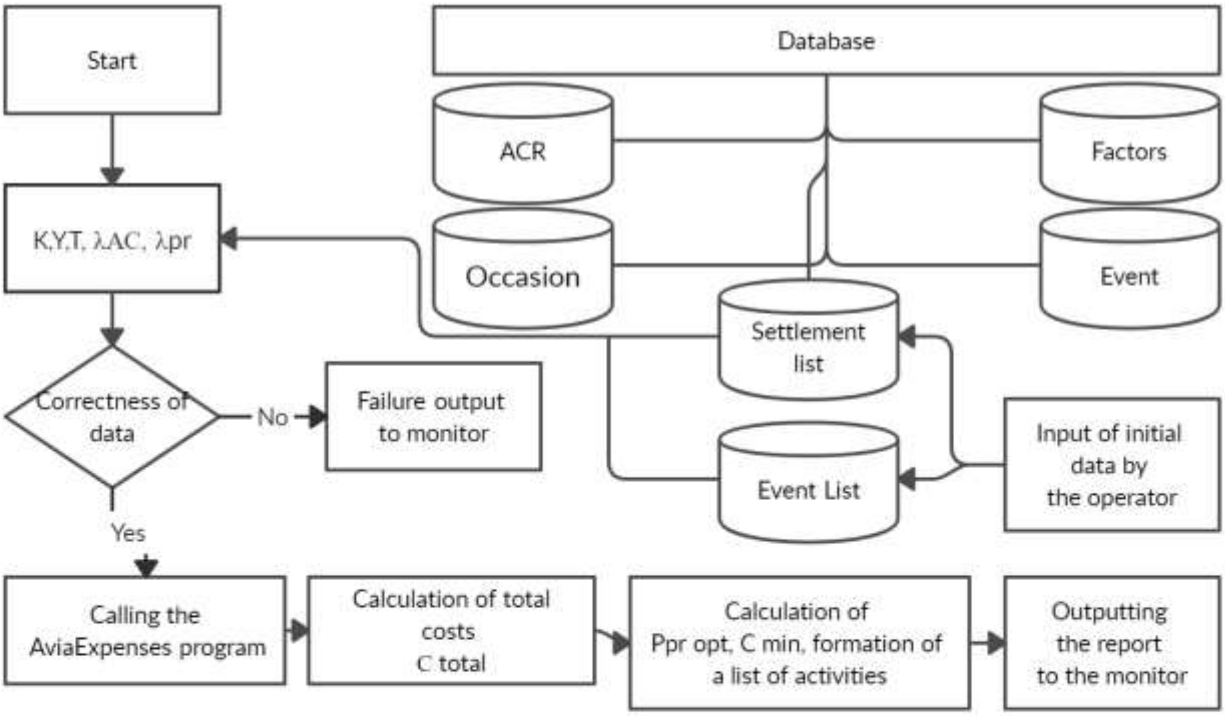
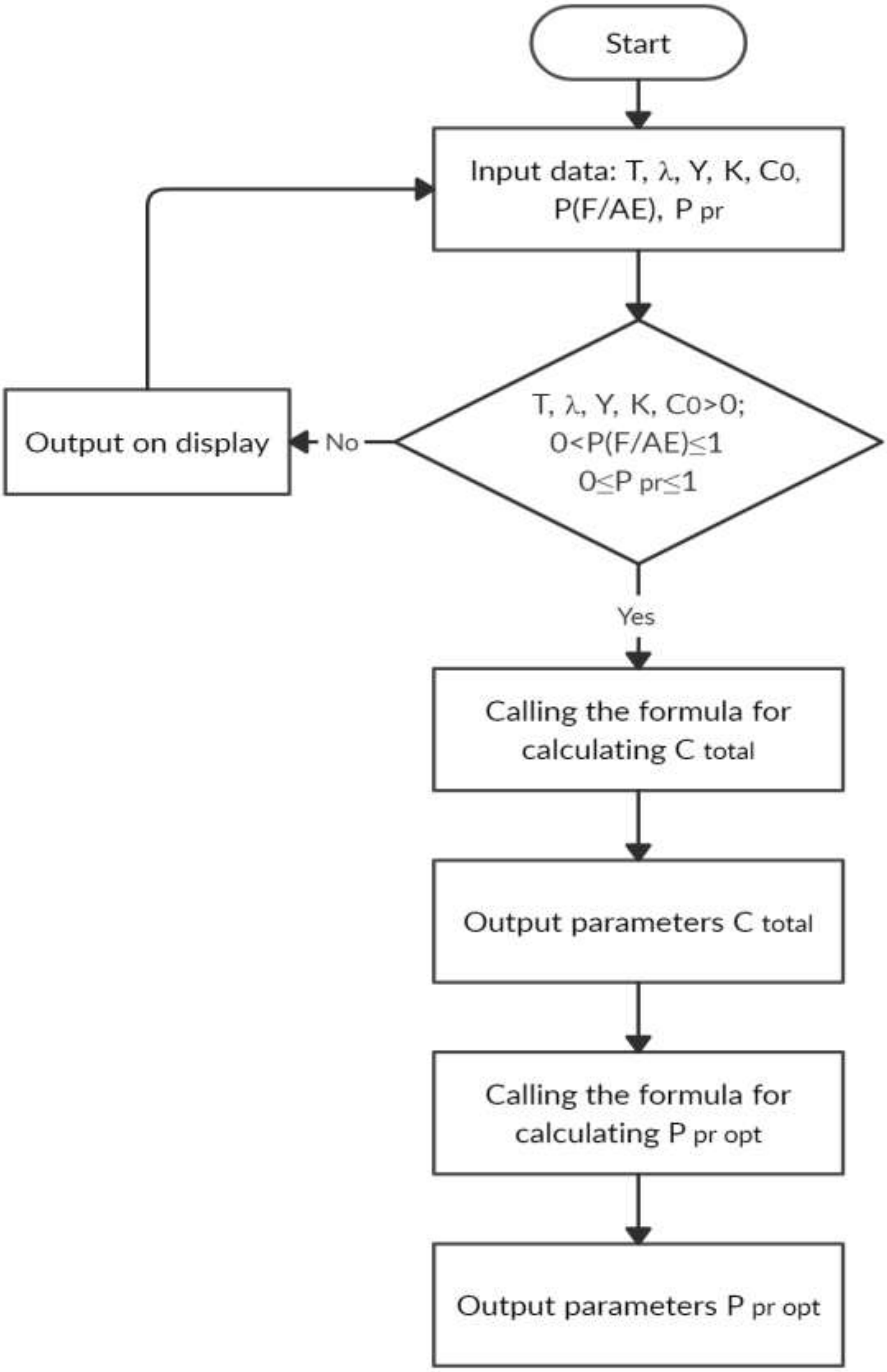


Figure 3.1 - Block diagram of the computational operations of the program

The operator, after filling the database on aircraft, factors, risk reduction measures and events, will form the calculation conditions.

After checking the correctness of all parameters, the program will calculate the total costs, the minimum total costs, the optimal prevention probability for all events. Block diagrams for calculating the listed parameters are shown in Figures 3.2, 3.3.

Also, in the developed in future version of the program, a list of the most effective measures with minimum total costs and maximum risk reduction should be formed from the database. The flowchart for generating the report is shown in Figure 3.4.



T - flight time, hour; λ - event flow rate, час$^{-1}$; Y — damage from aviation events; K - costs of an event to reduce the risks of aviation events; C_0 - process constant; P(F/AE) - the conditional probability of an aviation event occurring due to F; P_{pr} probability of preventing aviation events; C_{total} - initial total cost in SMS; $P_{pr\ opt}$- optimal probability of preventing aviation events.

Figure 3.2 - Flowchart for calculating the initial total costs in SMS and the optimal probability of preventing aviation events

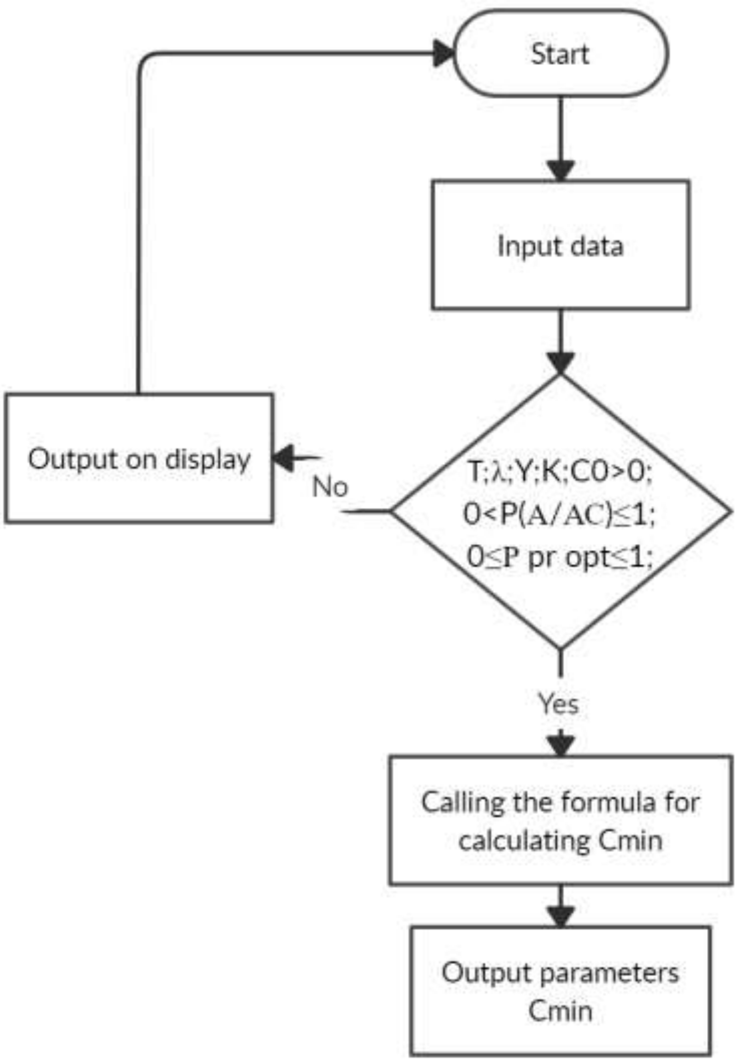
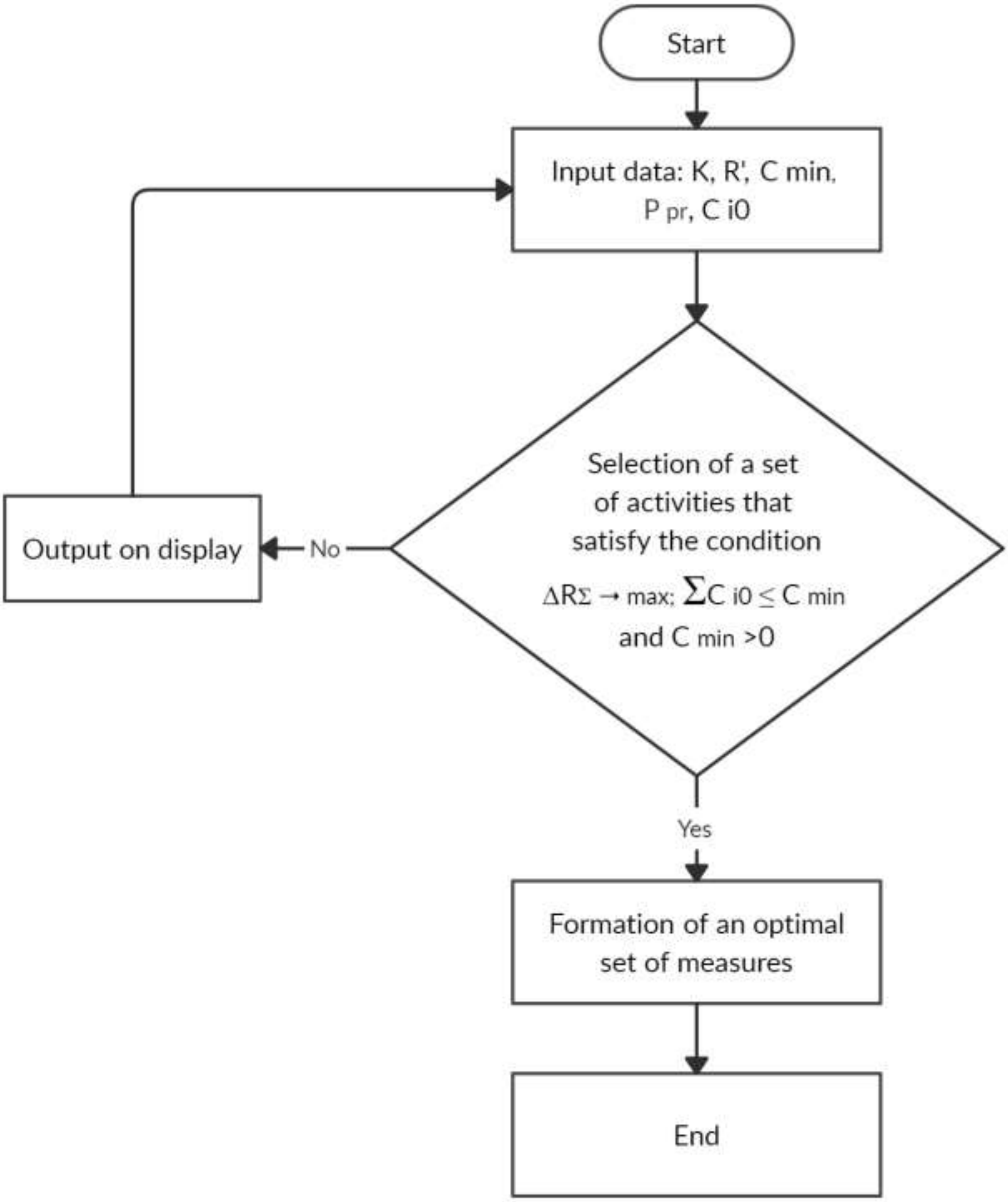


Figure 3.3 - Flowchart for calculating the minimum total costs



ΔR_{Σ} - total reduction in the risks of aviation events;

C_{i0}- total costs of preventing aviation events based on the results of the i_0 measure implementation, $(i_0 = \overline{1, m_0})$.

Figure 3.4 - Block diagram of the report generation

The generated report will be displayed on the user's monitor. The stored procedure contained in the software directly calculates C_{min}, C_{tot} и $P_{pr\ opt}$ and generates a list of activities.

3.5. Chapter 3 Conclusions

1. The developed software will allow not only to calculate the optimal probability of prevention and the corresponding minimum total costs, but also will form a list of measures to reduce aviation risks of events based on the value of the optimal probability of preventing aviation events. Such a set of measures minimizes risks at minimum total costs.

2. The software for calculating the optimal probability of preventing aviation events can be integrated into automated systems for determining and predicting the risks of aviation events. At the same time, it is possible to create an almost completely automated SMS.

3. The selected software building technologies will be easy and straightforward to use.

4. The database management system of the software for calculating the optimal probability of preventing aviation events allows you to store all information on all calculations performed in an unlimited volume, which makes it possible to track the effectiveness of reducing the risks of aviation events at various stages of calculations.

CHAPTER 4. OPTIMIZING THE PROCESS OF MANAGING THE RISKS OF SERIOUS INCIDENTS IN THE OPERATION OF CIVIL AVIATION AIRCRAFT USING THE SOFTWARE TO CALCULATE THE OPTIMUM LIKELIHOOD LIKELIVITY OF PREFERENCE

4.1. Calculation of the optimal probability of preventing aviation events during the operation of civil aviation aircraft and the corresponding minimum total costs

Using the software for calculating the optimal probability of preventing aviation events, a set of sixteen measures can be optimized to reduce the risks of serious incidents during the operation of sixteen commercial civil aviation aircraft (Table 4.1), such as A 319, A320, ATR 72/42, Yak-42, An-24, An-26, CRJ, An-28, B737, Pilatus, Tu-204, An-24.

To prepare the initial data for the calculation, the materials of the Interstate Aviation Committee for the investigation of serious incidents (rough landing, rolling out, landing under meteorological conditions below the established minimum) were analyzed, which occurred due to the human factor.

It is important to note that the use of the method for optimizing the process of managing the risk factors of aviation events is assumed on the basis of a predictive strategy for managing risk factors.

Due to the limited initial data for calculations and in order to confirm the reliability of the proposed method, the recommendations developed by the Interstate Aviation Committee following the investigation of each event were adopted as measures to reduce the risks of aviation events. The determining factor in all serious incidents is crew damage. The main measures to prevent the factor, therefore, to reduce the level of risks of serious incidents, are measures aimed at training aviation personnel, for practicing crew actions on simulators.

Table 4.1 - Measures to reduce the risks of serious incidents

Event ID	Aircraft type	Event	Prevention recommendations
1	2	3	4
1	AN-26V100	Rollout off the runway	1.With the flight crew, re-study the peculiarities of the approach using inaccurate systems; 2. Take into account the peculiarities of piloting from the action of a tailwind when choosing a working strip; 3. Practicing actions on the simulator.
2	A-320	Landing in meteorological conditions below the operating minimum	1. To organize a repeated explanation of the crew's actions when receiving information about the discrepancy between the meteorological minimum at the point of the final stage of the landing approach upon visual contact of the crew with landmarks; 2. Practicing actions on the simulator.
3	A-319	Landing in meteorological conditions below the operating minimum	1. In the Flight Operations Department of the airline to conduct an extraordinary debriefing and classes on the topic "Decision-making on the continuation of the approach at various stages of the approach when the weather conditions deteriorate below the operating minimum of the aerodrome"; 2. Practicing actions on the simulator.
4	Tu-204-100V	Rough landing	1. With the flight crew of airlines, re-study and practice actions to correct errors during aircraft landing;

			2. Practicing actions on the simulator.
5	A-320	Rough landing	1.Organize training sessions with the A-320 aircrew to study the design features of the aircraft and the crew's actions to correct errors during landing.
6	ATR-42-320	Landing in meteorological conditions below the operating minimum	1. Re-examine with the airline's command and flight personnel general rules for performing flights, descent, approach and landing; 2. Practicing actions on the simulator.
7	ATR-72	Rollout off the runway	Consider the features of the behavior and control of the ATR72 aircraft during the take-off run and the run, taking into account the accumulated experience of aircraft operation, develop a unified methodology for aircraft control at these stages, and work out on the simulator.
8	ATR-42-300	Rollout off the runway	Airline management: 1. To oblige the commanders of the aircraft to make entries in the aircraft logbook after the completion of the flight about all known or suspected defects on the aircraft; 2. With the flight crew of the ATR42-300 aircraft, in order to study the method of correcting typical errors on landing, conduct classes on the topic: "Landing on a runway with a low friction coefficient"; 3. Develop measures to improve the quality of operational maintenance of the aircraft.

9	An-24RV	Rough landing	1. When flying to an aerodrome, the crew at a pre-flight briefing should receive information about the quality of the preparation of the runway; 2. Re-study and practice actions to correct errors during aircraft landing;
10	Yak-42	Rollout off the runway	Modify the spoiler control system on all operated Yak-42 aircraft in order to enable their forced release by the crew.
11	A-321	Rollout off the runway	1. To the airline's management to equip the flight information section with equipment for decoding the data of voice and sound information recorders from A319 / 320/321 aircraft; 2. Airport management: - to install an indication board of actual weather meteorological elements in the aerodrome service room; - consider the possibility of relocating the aerodrome service premises; - consider the possibility of installing video cameras to ensure registration of the situation at the runway.
12	CRJ-200	Landing in meteorological conditions below the operating minimum	With the flight crew of the airline, re-examine the descent, approach and landing, work out the actions on the simulator;
13	Boeing	Rough landing	Conduct additional classes with the airline's

	737-500		flight personnel to study crew actions in case of suspected rough landing.
14	Pilatus PC-12/47	Rough landing	With the flight crew of the airlines, re-study and practice actions to correct errors during aircraft landing.
15	An-24	Rough landing	With the flight crew of the airlines, re-study and practice actions to correct errors during aircraft landing.
16	An-28	Rollout off the runway	With the flight crew, conduct a re-study of the peculiarities of the approach using inaccurate systems set out in the airlines' manuals.

Table 4.2 - Initial data for calculating the optimal probability of preventing serious incidents

Code	Aircraft type	Total expected risk, UAH million	Cost of events, UAH	P_{pr}	λ	Economic efficiency of measures, million UAH
1	1	2	3	4	5	6
1	An-26B-100	1,02	36209	0,99	$0{,}4 \cdot 10^{-4}$	0,066
2	A-320	34,56	316830	0,99	$0{,}5 \cdot 10^{-4}$	34,00
3	A-319	19,85	316830	0,99	$0{,}3 \cdot 10^{-4}$	19,61
4	Tu-204-100B	8,147	111173	0,99	10^{-4}	7,95

5	A-320	28,5	105610	0,5	$0{,}3{\cdot}10^{-4}$	13,84
6	ATR-42-320	49,41	149363	0,99	$0{,}5{\cdot}10^{-4}$	48,77
7	ATR-72	48,28	90523	0,99	$0{,}2{\cdot}10^{-4}$	47,90
8	ATR-42-300	55,07	149363	0,99	$0{,}5{\cdot}10^{-4}$	54,37
9	An-24RV	4,68	56576	0,99	$0{,}5{\cdot}10^{-4}$	4,60
10	Yak-42	3,53	37717	0,99	$1{,}1{\cdot}10^{-4}$	3,49
11	A-321	198,02	211220	0,99	$1{,}2{\cdot}10^{-4}$	195,76
12	CRJ-200	3,12	60348	0,99	$0{,}4{\cdot}10^{-4}$	3,03
13	B 737-500	121,45	211220	0,33	$0{,}7{\cdot}10^{-4}$	36,29
14	PC-12/47	2,72	74115	0,33	10^{-4}	0,74
15	An-24	2,51	56576	0,99	$0{,}5{\cdot}10^{-4}$	2,43
16	An-28	0,45	37717	0,99	$0{,}3{\cdot}10^{-4}$	0,41

The cost of activities for practicing actions on simulators is absolutely theoretical and apprixomate for somilation.

The initial data on the intensity of the corresponding streams of aviation events for each type of aircraft were calculated based on the statistical data of the international organization "Air claims World Aircraft Accident".

4.2. Directions for further development of the method for calculating the optimal probability of preventing aviation events

When calculating the optimal probability of preventing aviation events $P_{pr\ opt}$, all types of risks of aviation events that can lead to aviation accidents and various consequences, including environmental damage, damage to third parties, can be taken into account.

When calculating the value of $P_{pr\ opt}$ and the corresponding costs, insurance of aviation risks can be taken into account. ICAO does not view the insurance process as risk management, but airlines may take insurance into account when preparing the financial and economic justification for SMS management decisions.

As you know, aviation insurance or insurance of aviation risks includes risks arising from the operation of an aircraft. There are two types of aviation insurance:

- aircraft hull insurance (damage, loss, loss of aircraft);

- insurance of civil liability of aircraft owners to passengers and third parties:

- insurance of the air carrier;

- insurance of the air carrier before passengers for loss of life or injury;

- insurance of the air carrier for the loss or damage to baggage;

- insurance of liability to third parties on the ground and in the air for causing harm to them, as well as damage to their property as a result of the operation of an aircraft;

- crew insurance;

- liability insurance for the safety of goods transported by air;

- insurance against third parties during aircraft construction or repair work;

- insurance of any other property interest related to the operation of air transport.

The amount of insurance payments is provided for by insurance contracts, which are concluded between the insurer (insurance company) and the policyholder (airline) on various terms depending on the aircraft fleet, types of flights performed, flight safety and other factors. Considering that some of the risks and their potential damage will be insured, $P_{pr\ opt}$ will take the value (for example, catastrophes):

$$P(M_{\text{КХ}}/\Phi_{\text{Ка}})_{opt} = 1 - \frac{\sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0\text{Xa}}}{\sum_{q=1}^{v} \begin{gathered} T_q\Big(\sum_{\alpha=1}^{\mu}\lambda_{qK_\alpha}\cdot\sum_{a=1}^{m}\text{P}\left(\frac{\Phi_{\text{Ка}}}{\text{К}_\alpha}\right)\cdot\overline{C_{q\alpha a}} + \\ + \sum_{\alpha'=1}^{\chi}\lambda_{qK_{\alpha'}}\cdot\sum_{a=1}^{m}\text{P}\left(\frac{\Phi_{\text{Ка}}}{\text{К}_{\alpha'}}\right)\cdot\overline{C_{q\alpha' a}} + \\ + \sum_{\alpha''=1}^{\psi}\lambda_{qK_{\alpha''}}\cdot\sum_{a=1}^{m}\text{P}(\Phi_{\text{Ка}}/\text{К}_{\alpha''})\cdot\overline{C_{q\alpha'' a}}\Big) - R'' \end{gathered}} \quad (4.1)$$

where R" is the potential damage to the insured risks of aviation events.

$\text{P}_{pr\ opt}$ when insuring a part of the risks will take a lower value and, therefore, the total costs will be lower.

In addition to the above, for insurance, some insurance companies may provide for deductibles.

A deductible in insurance refers to the part of damage that is not reimbursed by the insurance company. Franchises are conditional, unconditional, dynamic.

In case of a conditional deductible, if damage is caused to the policyholder, the cost of which does not exceed the level of the deductible, insurance payments are not paid by the insurer to the policyholder, if it is exceeded, the insurer pays insurance benefits in full.

With an unconditional deductible, the deductible is always deducted from insurance payments.

With a dynamic deductible, the amount of non-refundable damage varies depending on the number of insured events.

Franchises also affect the calculation $\text{P}_{pr\ opt}$:

$$P(M_{КХ}/Ф_{Ка})_{opt} = 1 - \frac{\sum_{X=1}^{Z}\sum_{a=1}^{m} C_{0Xa}}{\sum_{q=1}^{v} \begin{matrix} T_q(\sum_{\alpha=1}^{\mu}\lambda_{qK_\alpha}\cdot\sum_{a=1}^{m} P\left(\frac{Ф_{Ка}}{К_\alpha}\right)\cdot\overline{C_{q\alpha a}} + \\ +\sum_{\alpha'=1}^{\chi}\lambda_{qK_{\alpha'}}\cdot\sum_{a=1}^{m} P\left(\frac{Ф_{Ка}}{К_{\alpha'}}\right)\cdot\overline{C_{q\alpha' a}} + \\ +\sum_{\alpha"=1}^{\psi}\lambda_{qK_{\alpha"}}\cdot\sum_{a=1}^{m} P(Ф_{Ка}/К_{\alpha"})\cdot\overline{C_{q\alpha" a}}) - R" + F \end{matrix}} \quad (4.2)$$

where F - is the size of franchise.

The calculation of $P_{пр\,opt}$ and C_{min},, taking into account insurance payments and deductibles, should be carried out based on the specific conditions of the insurance contract in relation to various risks.

Another promising direction for the further development of the developed method for optimizing the risk factor management process is taking into account the relationship between aviation events, factors of aviation events, the probability of transition of some aviation events to others, the impact of one measure to reduce the risks of aviation events on several factors.

4.3. Conclusions on chapter 4

1.Using the software, a set of 16 measures can be optimized to reduce the risks of serious incidents during the operation of commercial civil aircraft. As a result, with total costs calculated, risks will be reduced by the definite percentage and calculated cost.

2. In the course of calculations, results would be obtained, that would be able to confirm the effectiveness of measures to prevent aviation events developed based on the results of investigation, which confirms the reliability of the method used in the software for calculating the optimal probability of preventing aviation events.

3. The results of the calculations can be widely used by the aviation companies when managing the risk factors of aviation events in the SMS.

4. The main directions of the development of the method for calculating the optimal probability of preventing aviation events is taking into account insurance, deductible, the relationship of aviation events, factors and preventive measures that affect several factors simultaneously.

CONCLUSION

Thus, as a result of the study, proposals were prepared to improve the flight safety management system by applying the method of optimizing the process of managing risk factors of aviation events based on the criterion of minimum total costs. Main results of work:

1. The efficiency of accounting in the process of managing the risk factors of aviation events of the criterion of minimum total costs was revealed based on the results of the analysis of the operating SMS of airlines.

2. The developed mathematical model of total costs makes it possible to determine the level of increased flight safety with minimum total costs for ensuring flight safety and eliminating damage from aviation events during the operation of air transport.

3. The method of optimizing the process of managing risk factors, which was developed on the basis of a mathematical model of total costs, can allow to form a set of measures that reduce the risks of aviation events at minimum total costs. This method solves the “Protection and Production” dilemma in the airline's operations.

4. The method of optimizing the process of managing the risk factors of aviation events can be implemented in software that allows calculating the optimal level of improving flight safety (based on the criterion of minimum total costs) and automatically generating a set of measures from the database to achieve this level.

5. Using the software for calculating the optimal probability of preventing aviation events, a set of measures to reduce the risks of 16 serious incidents during the operation of 16 civil aviation aircraft can be optimized. As a result of optimization, the risk should be reduced by the calculated resulting percentage with a minimum total cost calculated, and economic efficiency.

6. The work of the software for calculating the optimal level of probability of preventing aviation events can be tested and implemented in the activities of the interested in safety management systems developing airlines.

7. The main directions of further development of the method for calculating the optimal probability of preventing aviation events is taking into account insurance, franchise, the relationship of aviation events, factors and preventive measures that affect several factors simultaneously.

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