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DETERMINING POSSIBILITIES FOR APPLYING THEORETICAL PRINCIPLES OF SITUATIONAL RISK MANAGEMENT IN THE AVIATION SAFETY SYSTEM

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Aviation safety is one of the main criteria for its sustainable development. The object of this study is safety risk management, which is the main tool of the aviation safety management system. The problem that needs to be further solved is the improvement of aviation risk management methods under war, force majeure, and crisis conditions, as well as under conditions of uncertainty, when there is a minimum of time to make a single correct decision. The theory of situational management can be chosen as the theoretical basis for creating decision-making systems. The development of special languages for describing the situation arising at the control object, as well as in its control system, makes it possible to correctly represent the models of control objects and the evolution of knowledge about them. The work solves the task of building a model of the control object, which takes into account the maximum number of its features suitable for implementation. In order to represent the management object based on the method of expert assessments, the weighting coefficients of the risk characteristics' probabilities and the values of the weighting coefficients of the degrees of severity were calculated, a matrix of risk assessment indicators was built, and risk assessment criteria were developed. Based on the calculations, general approaches to aviation safety risk management were specified. The paper developed a «dramatic script» of an episode of aviation safety risk management, which includes the stages of the episode, the content of necessary actions, the corresponding stages of aviation safety risk management and the corresponding aviation safety risk management. The content of the management itself consists in preventing the transition from the zone of acceptable risk to the zone of permissible and from the zone of permissible risk to the zone of unacceptable risk, as well as the implementation of measures to stimulate the transition from the zone of unacceptable to the zone of permissible risk and from the zone of permissible to the zone of acceptable risk

Keywords: risk management, aviation safety, situational management, frame structure, drama technology, human factor, nuclear language, area of acceptable risk, reactive, proactive, predictive management methods

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1. Introduction

Ukraine is an aviation country. However, for the second year in a row, the industry is actually operating under conditions of war. At first glance, the closure of the airspace on the first day of the war and the lack of commercial flights over its territory raises the question of the feasibility of finding a new toolkit of aviation risk management. In fact, under the conditions of war, the structure and degree of intensity of threats fundamentally changes, which leads to the emergence of a number of new risks. The first group of threats and risks is related to the organization of evacuation flights of aviation equipment under the threat of missile attacks. The second group of threats and risks is related to the commercial activities of Ukrainian air carriers from the territory of other countries, which actually operate at a distance from their bases and head offices, including those responsible for maintaining the appropriate level of safety. The third group of threats and risks is directly related to the maintenance of life support and preservation of mothballed airports and aviation equipment. This is a far from complete list of objects of research into the management of aviation safety changes under military conditions. Under such conditions, the importance of the human factor in the process of making managerial decisions comes to the fore, as a rule, under conditions of incomplete information and time limits. At the same time, the main problem is the preservation of human resources and maintaining their competence. Aviation specialists protect the Motherland, many women are forced to leave the country. At the same time, they lose their certification and practical skills. The task of the state leadership to return to full-fledged operational activity in the first months after the war requires the use of a proactive approach and the development of new approaches in aviation risk management. The aviation industry of Ukraine faces new challenges that call into question the effectiveness of existing aviation risk management systems and require the search for new approaches in the field of risk management.

The relevance of the study is related to the further development of the effectiveness of decision-making systems in aviation by applying the theory of situational management in the risk management system. At the same time, the topicality of the study has not only national but also regional and global significance. The industry crisis of 2020–2021, caused by the consequences of the COVID-19 pandemic, which in the first year led to a more than 70 percent decrease in commercial flights in various regions of the world, became a global challenge for world aviation. The problem of personnel shortage of certified professionals is acutely felt all over the world. The volumes of global and regional air transport are gradually returning to the pre-pandemic level but resource support for aviation safety is limited by the significant expenditure of the industry's resources during the pandemic years.

The development of risk management acquires special importance under military, force majeure, and crisis conditions, as well as under conditions of uncertainty, when there is a minimum of time to make a single correct decision. The International Civil Aviation Organization (ICAO) is directly involved in the development and search for new tools for proactive aviation risk management in the context of military operations. The ICAO Council has established and is actively developing the ICAO Conflict Zone Information Repository (CZIR), providing comprehensive information monitoring within its operational flight planning systems. States maintain and publish global aviation safety and aviation safety warning information on regional and national websites.

Therefore, the search for the newest tools of aviation risk management is a priority task of world civil aviation. Situational management of industry safety allows taking into account aspects of the human factor as one of the main factors of unpredictability. The use of proactive and predictive risk management methods makes it possible to manage safety in the early stages of the development of a catastrophic situation, to work with the prerequisites and not the consequences of a complex failure of the civil aviation system.

2. Literature review and problem statement

Work [1] examines the state and strategic scenarios for the restoration of the sustainable development of air transport in Ukraine in the post-war period. The study was carried out with a scientific justification of quantitative indicators and macro indicators of maintaining the trajectory of sustainable development in the medium term. However, the issues of developing a toolkit for operational aviation safety risk management under the conditions of war and post-war development, taking into account the human factor, remained unresolved. This allows us to assert that it is appropriate to conduct a study to consider situational management under conditions of uncertainty, which will allow qualitative adjustment of strategic scenarios.

Paper [2] provides a systematic review of the literature on technological advances in risk management, including methods in combination with reactive, proactive, and predictive measures that are currently used to reduce risks in the aviation sector. Predictive and interactive methods have been shown to create fault-tolerant systems, prevent accidents, and improve quality and safety systems by providing system feedback. But the questions regarding the practical application of these methods in force majeure and under conditions of uncertainty remained unresolved.

A number of works consider the choice of language in the process of managing safety risks. In work [3], the reporting structure for the investigation of aviation events of the EUROCONTROL organization, coordinated with EU and ICAO rules, is analyzed. A structured step-by-step proactive risk assessment strategy is proposed, starting with adverse event reporting. All of this is made possible by using a neutral language/taxonomy that facilitates modeling for both events and day-to-day operations. Natural language processing (NLP) approaches applied to areas related to aviation safety are considered in [4]. Problems and limitations of current applications of NLP in aviation are discussed, such as ambiguity, limited training data, lack of multilingual support. The review reveals the future possibilities of using NLP models to promote the safety and efficiency of the aviation system. The issue of further selection of the appropriate language of situational management for solving strategic and operational tasks of aviation risk management remains unresolved.

The negative impact of various aspects of the human factor on aviation safety was studied in [5], namely, the fatigue factor of aviation personnel was systematically studied as one of the key aspects of the human factor. The risk associated with fatigue in the aviation industry has been found to be diverse and sometimes ambiguous. At the same time, issues related to the negative aspects of the human factor in situational risk management remained unresolved. In [6], the characteristics of the pilot's behavior were used to build a model for assessing the risk of going off the runway. The proposed method makes full use of real airline flight data under various conditions, including pilot behavior, and can inform risk analysis of other hazardous events such as hard landing, tail strike, etc. Unresolved issues are a complex of issues related to effective decision-making by the pilot taking into account human limitations. In [7], the human factors analysis and classification system (HFACS) was investigated, which provides a hierarchical principle of classification of human errors in aviation accidents, and the system dynamics (SD) approach is useful for describing the risk development process. The simulation results also show that the recommended safety enhancement measures increase the stability of the aviation system and therefore reduce the overall accident rate. At the same time, issues related to the operational management of aspects of the human factor in the development of an aviation event remained unresolved. The review of works that consider the impact of the human factor on aviation safety allows us to state that it is appropriate to conduct a comprehensive study of aviation risk management tools, including the operational management of aspects of the human factor in the development of an aviation event. This will minimize the negative impact of human errors and violations in situational safety management.

An analysis of the development of tools for reactive, proactive, and predictive methods of aviation safety management was carried out. For example, in work [8], based on the analysis of historical passenger airline accidents, a four-stage procedure was formulated for building a Bayesian network for fixing cause-and-effect relationships embedded in the sequence of these accidents. In order to estimate the conditional probabilities in the Bayesian network, a monotonically increasing function was developed, the parameters of which are calibrated using information about the probabilities of individual events in the available data. It facilitates both forward propagation and reverse inference in probabilistic analysis, thus supporting accident investigation and risk analysis. The specified approach makes a significant contribution to the development of reactive safety management methods, but issues related to operational decision-making in the event of a negative scenario of the situation remain unresolved. In [9], a prognostic model was developed for studying a wide range of possible cases and quantifying aviation risk. The effectiveness of the hybrid model in quantifying the risk associated with the consequences of hazardous events has been demonstrated. In [10], a predictive flight path model was developed, which is a vital tool for improving the safety management of the national airspace system. The prediction model is implemented as a high-precision flight dynamics simulator to simulate the response of the aircraft after a crash. In addition, a data-driven deep learning surrogate model is built to increase the computational power of such risk region estimation. At the same time, the issues of connection of these prognostic approaches with reactive and proactive methods of aviation safety management remained unresolved. The review of works that consider the development of the toolkit of reactive, proactive, and predictive methods of aviation safety management allows us to state that it is appropriate to use the approaches of compiling reactive, proactive, and predictive methods of aviation safety management, which will make it possible to quickly minimize the influence of dynamic negative factors.

The research in the field of situational management and frame theory is actively being conducted. And in the work, in work [11] it is shown that locally compact abelian (LCA) groups form a natural environment for the theory of frames in signal processing. For illustration, specific constructions of pairs of double frames for several LCA elementary groups are given. The ability of fuzzy set theory to offer a mathematical framework for the integration of arbitrary categories represented by membership functions is one of its most attractive aspects. But the difficulty arises when the number of criteria to be considered increases. In [12], a new concept called «ordered weighted aggregation operators on several sets» was proposed, which minimizes the difficulty of considering options. The paper considers the introduction of aggregation operators and ordered weighted aggregation operators in several sets. Along with certain key conclusions, a theoretical discussion based on them was also conducted.

In [13], some basic definitions and results regarding continuous frames, continuous *g*-frames, equivalence relations, and distances between continuous *g*-frames are given. In addition, some equivalence relations between continuous *g*-frames for a Hilbert space and closed subspaces in L2(A) are introduced, and the distance between continuous *g*-frames is defined. A new metric on a set of almost continuous *g*-frames is proposed and some of its properties are investigated. At the same time, the questions of the practical application of situational management methods and the theory of frames in solving the problems of aviation risk management remained unresolved.

So, despite the large number of publications on the researched topic, the decision-making process in complex dynamic aviation systems is not a fully resolved part of the problem. Successful promotion of aviation safety is associated with the ability to anticipate changes in trends, high speed, and flexibility of response, as well as timely strategic decision-making. For the effective development of the aviation safety management system, it is currently necessary to devise modern methods and tools to support responsible decision-making at various levels. Using the theory of situational management and the theory of frames to solve the problems of aviation risk can make a significant contribution to the process of maintaining an acceptable level of aviation safety.

3. The aim and objectives of the study

The purpose of our study is to determine the possibilities of applying theoretical aspects of situational risk management in the aviation safety system.

To achieve the goal, the following tasks were formulated:

– to develop aviation safety risk assessment criteria based on the weighting coefficients of the probabilities of the risk characteristics, the value of the weighting coefficients of degrees of severity;

– to devise a «dramatic scenario» of an episode of situational risk management in the aviation safety system;

– to develop an example of using the nuclear language of situational management to describe a fragment of a dangerous aviation situation based on the frame approach.

4. The study materials and methods

The object of research in our work is safety risk management, which is the main tool of the aviation safety management system. Risks in the aviation safety system belong to the «complex» class. For such objects, accurate mathematical models built in the form of a system of algebraic equations and a system of differential equations are incomplete, or completely inadequate to the object of modeling, or unsuitable for implementation on existing computing devices. Aviation safety risks do not have the properties of traditional objects of management, which is explained by the following reasons: uniqueness, lack of a formalized purpose of existence, lack of optimality criteria, dynamism, incomplete description, presence of freedom of will. The uniqueness of aviation safety risks is the presence of specific structural and functional features that do not allow the use of a known typical standard management procedure.

The lack of a formalized purpose for the existence of the management object under consideration significantly complicates the formation of a single equation criterion. This leads to a rather cumbersome system of various criteria, which in turn makes it impossible to state a classic optimization problem for aviation safety. The result of the above is that the system of management criteria becomes subjective, depending on the «regulator».

The lack of a real group of experts capable of unambiguously interpreting the management object under consideration and providing a sufficient amount of information to create a management system for the object leads to incompleteness and subjectivity of the description.

A situational approach [14] is proposed for the synthesis of the aviation safety risk management system. Situational management will make it possible to increase the effectiveness of aviation risk management under war, force majeure, and crisis conditions, as well as under conditions of uncertainty.

At the same time, aspects of the human factor will be taken into account, as one of the main factors of unpredictability. The human factor acts both as an object and as a «regulator» of the system itself. This significantly affects the formation of specific, compared to purely technical systems, management influences at the stage of functioning, a significant part of which is subjective. In the work, the concept that is an organic basis for perception, measurement, and management of aviation safety risks is singled out from the various definitions of risk that exist today. The hypothesis of the study was the opinion that aviation safety risks involve the perception of a system of threats specified in the relevant nomenclature documentation.

The International Civil Aviation Organization (ICAO) provides the following definitions of aviation safety threats. A threat is a state, object, or activity that is a potential cause of death or injury to personnel, damage to equipment or structures, material losses, or a reduction in the ability of personnel to perform their assigned functions [15]. Risk can be understood as the possibility of loss or damage, which is measured by the degree of severity and probability [15].

To represent the object of management, it is advisable to apply the numerical matrix of risk assessment indicators (M_{RAI}):

$$M_{RAI}=[m_{AR}]_{5\times 5},$$

where

$$m_{AR}=p_i \cdot s_k,\ i,k=\overline{1,5}, \quad (1)$$

p_i is the value of the probability weighting coefficients; s_k – the value of the weighting coefficients of degrees of severity.

From a mathematical point of view, the dimensionality of the M_{RAI} matrix results from the number of degrees of severity of events and the number of types of risks. Also, from a mathematical point of view, the «squareness» of M_{RAI} is not a predetermined requirement. Generally speaking, the specified numbers are the result of the work of researchers, developers, but the International Civil Aviation Organization (ICAO) considers five degrees of severity of events and five types of risks [15].

To obtain the values of weighted probability coefficients (p_i) and the values of weighted coefficients of degrees of severity (s_k), the classical method of expert evaluations was used [16].

The numerical matrix of risk assessment indicators allows formulating the trajectory of risk management.

For the effective management of aviation safety risks, a correct, adequate, and understandable description of the management object for formalization is necessary, taking into account, in particular, its specific structure, functioning and behavior of people involved in its possible evolution over time. The scheme of the situational management of aviation safety risks can be represented as follows (Fig. 1).

To create this description, an approach is needed that makes it possible to represent both the management object and its functioning, as well as its management scenarios, in one formalization language. By analogy with the general theory of situational management, the following definitions are used to pose the problem of aviation safety risk management:

– definition 1. The current situation in the risks of the aviation safety system is called the totality of all reliable knowledge about its obvious structure and threats to the functioning of the system during a given period of time t and is denoted by PS_t;

– definition 2. The comprehensive situation in the aviation safety risk system is called the totality, which includes the current situation and knowledge about the state of the aviation safety risk management system, its active and passive protection, as well as vulnerabilities for a given period of time and risk management scenarios and is denoted by VS. If the control system has k different ways of influencing the object (dramatic episodes), then each such episode is denoted by e.

Then the elementary fact of management is represented by the scheme:

$$VS_t : PS_i \overrightarrow{e_{ij}} PS_j.$$

Based on the principles of situational control, the scheme reflects the fact of determining the state of the control system, the content of control at the moment of time t VS_t. The control object, being in the PS_i situation at time i and under the influence e_{ij} (one-step decision of the management process), moves to the PS situation at time j. The rules of this transition are called either logical transformation rules (LTP) or correlation rules. The set of LTP creates conditions for the control system to influence the state of the control object.

The task of aviation safety risk management is to ensure conditions that allow maintaining risk assessment indicators in an acceptable zone.

Hypothetically, the scheme for solving the problem of managing the situational risks of aviation safety may look as shown in Fig. 1.

Situational management involves the conscious writing of the structure, functioning of the object of management, as well as the features of its management, that is, the construction of both semantic and pragmatic formal models, and therefore, special linguistic means for describing such models.

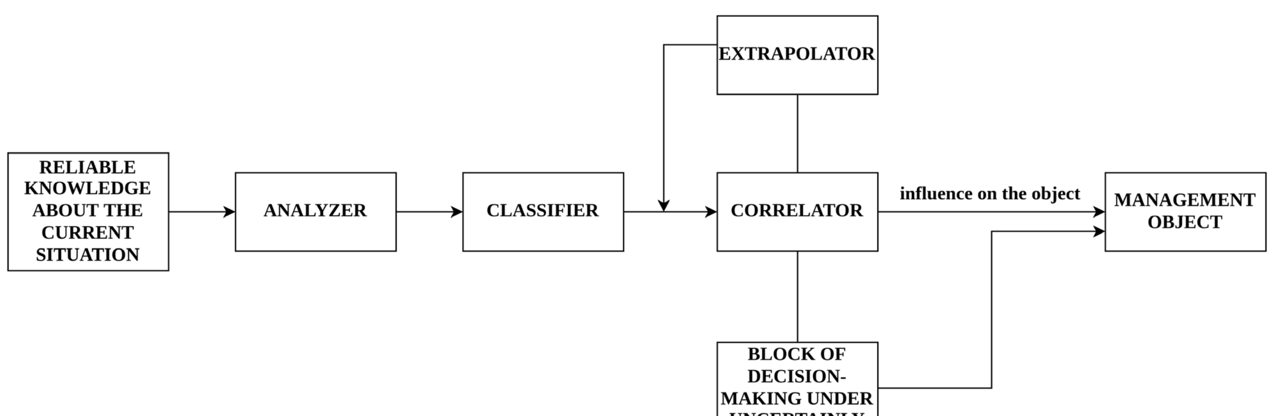

Fig. 1. Scheme of the system of situational management of aviation security risks

Situational management languages take into account the basic laws of natural language construction for situational management. Natural language uses constructions that allow expressing concepts, relations, and roles in the management process. Therefore, for the use of a simple nuclear language in these studies, the following classical groups were used: MSU for computer processing can be transformed into a knowledge representation language (KRL). Some KRLs use frame structures for a compact, consistent, and understandable description of specific facts, events, phenomena, and processes.

Using the language of situational management, it is possible to describe the management process based on the game-theoretic approach of «Dramatek». «Drama-technology» is the most promising technology for creating and modeling possible scenarios of the development of situations, their possible results, and consequences in situational management. It extends certain limitations of classical game theory to drama theory by means of metagame modeling. The scenario of the dramatic development of the situation and the management of the object that falls into it, but does not have a rational solution, rational behavior in it, involves the transformation of the original game into a new one in which they exist. The purpose of drama analysis is to identify contradictions between the tasks of object management and the current situation, and the purpose of game analysis is to find an optimal (or at least acceptable) solution.

From the point of view of the game-theoretic approach, aviation safety risks can be considered as a game with nature. In our paper, nature refers to a set of factors affecting aviation safety. The player is a set of services that contribute to its strengthening. Taking into account the experience of readiness for continuous professional development, initiative, and individual abilities of the representatives of these services generalizes the game-theoretic approach into the theoretic-dramaturgical one. This approach, in particular, involves the division of a rather complex drama into several interconnected episodes of the same structural type. Aviation safety risk management necessarily includes a psychological-cybernetic component, the purpose of which is to create and use intelligent systems, in particular, decision-making. The theoretical basis for creating such systems can be the ever-developing theory of situational management, which is used to solve large-scale problems when traditional methods and approaches are powerless. The development of special languages for describing the situation arising in and on the management object, as well as in its management system, makes it possible to correctly represent the models of management objects and the evolution of knowledge about them. The representation of knowledge and its evolution can be conveniently implemented using the classical theory of frames.

5. Results of investigating theoretical aspects of situational management of aviation safety risks

5. 1. Aviation safety risk assessment criteria

In the aviation safety management system, the presence of aviation events (disasters, serious incidents, and incidents) is not the only indicator of the state of the system. Rather, it is an indicator of a complex system failure that is subject to management by proactive methods at the stages of preventing an aviation event. However, during the war, a number of aviation events occur, the disclosure of which in open sources is inadmissible under current conditions. At the same time, the purpose of the study is in no way related to the investigation of aviation events but is aimed at preventing and eliminating them. Therefore, the classic method of expert evaluations was used within the framework of our studies on the criteria for assessing the risk of aviation safety [16].

The expert group consisted of four experts; they were highly qualified aviation safety specialists, including ICAO instructors.

After processing the results of the surveys, the values of the weighting coefficients of probability (p_i) and the values of the weighting coefficients of degrees of severity (s_k) were obtained, which are given in Tables 1, 2. Calculations were performed using MS Excel tools.

Table 1

Values of probability weights (p_i)

i	Characteristics of risk	p_i
1	Frequent	0.9
2	Periodic	0.7
3	Rare	0.45
4	Unlikely	0.24
5	Practically impossible	0.1

Table 2

The value of the weighting coefficients of degrees of severity (s_k)

Value of k	1	2	3	4	5
Categories of the degree of severity	A	B	C	D	E
Indicators of the degree of severity (s_k)	1	0.8	0.6	0.4	0.2

The assessment of the adequacy of the results is the obtained value of the concordance coefficient W (the overall rank correlation coefficient for the involved group of m experts) according to the formula:

$$W=\frac{12\cdot S}{m^2\left(n^3-n\right)},$$

$$S=\sum_{i=1}^{n}\left[\sum_{j=1}^{m}x_{ij}-\frac{1}{2}\cdot m\cdot\left(n+1\right)\right]^2,$$

where m is the number of experts; n is the number of compared objects; x_{ij} is the rank assigned to the i-th object by the j-th expert.

According to the results of calculations, the concordance coefficient W for the involved group of four experts is 0.93. The obtained value is sufficiently close to 1, which indicates a satisfactory consistency of experts' assessments.

In accordance with (1), a matrix of aviation safety risk assessment indicators M_{RAI} was built:

$$M_{RAI}=\begin{pmatrix} 0.9 & 0.72 & 0.54 & 0.36 & 0.18 \\ 0.7 & 0.56 & 0.42 & 0.28 & 0.14 \\ 0.45 & 0.36 & 0.27 & 0.18 & 0.09 \\ 0.24 & 0.192 & 0.144 & 0.096 & 0.048 \\ 0.1 & 0.08 & 0.06 & 0.04 & 0.02 \end{pmatrix}.$$

An example of finding risk assessment criteria (intervals of relevant risk zones) for an acceptable risk zone:

– the left end of the interval: min (0.36; 0.18; 0.42; 0.28; 0.14; 0.36; 0.27; 0.18; 0.24; 0.192; 0.144; 0.1)=0.1;

– the right end of the interval: max (0.36; 0.18; 0.42; 0.28; 0.14; 0.36; 0.27; 0.18; 0.24; 0.192; 0.144; 0.1)=0.42.

The number of zones and the corresponding elements of the M_{RAI} matrix correspond to the safety risk matrix of the International Civil Aviation Organization (ICAO).

The calculated M_{RAI} matrix makes it possible to identify the risk assessment criteria given in Table 3.

Table 3

Risk assessment criteria

Risk assessment indicators	Area of risk
[0.45–0.9]	Zone of unacceptable risk
[0.1–0.42]	Permissible risk zone (operational risk management zone)
[0.02–0.096]	Zone of acceptable risk (zone of strategic management)

The numerical matrix of risk assessment indicators allows formulating the trajectory of risk management. Limit values of risk zones require special attention. Aviation safety risk management means:

– measures to prevent the transition from the zone of acceptable risk to the zone of unacceptable risk (operational management);

– measures to prevent the transition from the zone of acceptable risk to the zone of acceptable risk (strategic management);

– measures facilitating the transition from the zone of unacceptable risk to the zone of acceptable risk (operational management);

– measures contributing to the transition from the zone of acceptable risk to the area of acceptable risk (operational management).

In the process of obtaining new information on the occurrence of aviation safety threats, data on new aviation accidents, the values of the weighting coefficients of probability and the values of the weighting coefficients of degrees of severity are recalculated, which in turn updates the matrix of aviation safety risk assessment indicators and the intervals of the corresponding risk assessment indicators.

5. 2. «Dramatek-scenario» of the episode of situational risk management in the aviation safety system

The development of the drama episode of aviation safety risk management on the example of an airline that opens a flight to a high-altitude airfield (episode model) is given in Table 4.

Table 4

Drama development of the aviation safety risk management episode using the example of an airline opening a flight to a high-altitude airfield (episode model)

No. of entry	Stages of the episode	Content of actions	Stages of aviation safety risk management	Aviation safety risk management on the example of opening an airline flight to a high-altitude airfield
1	2	3	4	5
1	End of the drama	Understanding the original problem. Development of possible ways to solve it	Constant monitoring of natural, technical, economic and anthropogenic threats	Natural threats: 1. Sudden weather changes. 2. Poor visibility. 3. Wind shear. 4. Thinning of the air. 5. Presence of natural obstacles (mountain massif). Technical threats: 1. Reduction of engine power. 2. Failure of the aircraft's engine or systems at high altitude. 3. Restrictions on type of aircraft and maximum load. Economic threats: 1. Frequent cancellations and postponements of flights due to natural hazards. 2. Restrictions on type of aircraft and maximum load. Human threats: 1. Violation of standard procedures by the crew during take-off/landing in the area of the high-altitude airfield. 2. Violation by the crew of enhanced procedures during takeoff/landing in the area of a high-altitude airfield
2	Development of drama	Formation of positions of drama participants and information about their actions	Identification and prioritization of a set of risks. Assessment of each risk according to the «Probability» and «Severity» scales	1. Collision of an aircraft with an obstacle (mountain massif) – 3A (3 – rare, A – catastrophic). 2. The fall of the aircraft due to a shortfall to the runway – 2A (2 – unlikely, A – catastrophic). 3. The plane goes beyond the runway – 2A (2 – unlikely, A – catastrophic). 4. Airline losses associated with frequent flight cancellations and postponements due to natural causes – 4C (4 – periodically, C – significantly). 5. Reduction in the level of expected income due to restrictions on the type and maximum loading of aircraft – 4D (4 – periodically, D – to a small extent)

Continuation of Table 4

1	2	3	4	5
3	The climax of the drama	Awareness of the incompatibility of the positions of the participants in the drama and the search for a compromise in the process of transforming positions. Establishing a positive or negative result of the search for a compromise of positions	Definition of the «zone» of risk: – green zone – acceptable under existing conditions; – the yellow zone is conditionally acceptable when developing and implementing a set of measures to reduce either the «Likelihood» or the «Degree of Severity» or both «Likelihood» and «Degree of Severity»; – red zone – the risk is unacceptable under the existing conditions. Action is possible only after reducing the risk to the «yellow zone» by developing and implementing a set of measures to reduce either the «Likelihood» or the «Severity» or both «Likelihood» and «Severity»	«Red zone» – the risk is unacceptable under the existing conditions: 1. Collision of an aircraft with an obstacle (mountain massif) – 3A (3 – rare, A – catastrophic). «Yellow zone» is conditionally acceptable when developing and implementing a set of measures to reduce either «Likelihood» or «Severity» or both options. 2. The fall of the plane due to the shortfall to the runway – 2A (2 – unlikely, A – catastrophic). 3. Departure of the aircraft outside the runway 2A (2 – unlikely, A – catastrophic). 4. Airline losses associated with frequent flight cancellations and postponements due to natural causes – 4C (4 – periodic, C – significant). 5. Reduction in the level of expected income due to restrictions on the type and maximum loading of aircraft – 4D (4 – periodically, D – to a small extent)
4	A positive resolution to the drama	Justification of the compatibility of the participants' positions. Proving that all outcomes are worse than the option that represents the general position of the participants and the impossibility of its guaranteed improvement, that is, that a single and stable equilibrium point for the drama has been found	Adopting a set of measures to reduce the vulnerability of the system at the level of equipment/technology, rules and regulations, training and inspections. Distribution of responsibilities, terms and sequence of measures, resource provision. The expected result is a guaranteed transition to the zone where it is possible to continue the activity, taking into account the result of the cost/benefit assessment	Adoption of a priority set of measures to exit the red zone, which determines the impossibility of flights: – at the level of technique/technology: 1) selection of the most technically sound aircraft; 2) modernization of the aircraft with wind shear detection devices; – at the level of norms and rules: 1) flight restrictions by time of day; 2) flight restrictions due to visibility conditions; 3) development of enhanced take-off/landing procedures in the area of the high-altitude airfield; – at the level of training and inspections: 1) practice with the crews of enhanced take-off/landing procedures in the area of the high-altitude airfield; 2) simulator training of crews during take-off/landing at a high-altitude airfield; 3) simulator training of crews for takeoff/landing at a high-altitude airfield in stationary mode; 4) simulator training of crews for take-off/landing at a high-altitude airfield in conditions of engine or aircraft system failure; – clear division of duties; – determination of time and sequence of measures; – adequate resource support; – the expected result is a guaranteed transition to the zone of the possibility of continuing the activity (1 – practically impossible A – catastrophic), taking into account the result of the cost/benefit assessment
5	Antagonistic stage	If the result of the search for compatibility of positions is negative, planning to maintain and improve positions in the process of deepening the conflict	Development of an inadequate set of measures to reduce the vulnerability of the system at the level of equipment/technology, rules and regulations, training and audit. Violations or shortcomings in aspects of the distribution of duties, terms and sequence of activities. Insufficient resource provision or economically impractical cost of a set of risk reduction measures. And, as a result, it is impossible to guarantee the transition to the zone of the possibility of continuing the activity, taking into account the result of the cost/benefit assessment	Development of an inadequate set of measures to reduce the vulnerability of the system at the level of technology/technologies, rules and regulations, training and audits. Violations or shortcomings in aspects of the distribution of duties, terms and sequence of activities. Insufficient resource provision or economically impractical cost of a set of risk reduction measures. And, as a result, it is impossible to guarantee the transition to the zone of the possibility of continuing the activity, taking into account the result of the cost/benefit assessment. If the risk does not reach the zone where it is possible to continue operations, the airline will refuse to fly to the high-altitude airfield
6	Implementation stage	Implementation of the plans developed during the development of the drama of this episode	Implementation of a set of measures to reduce the vulnerability of the system at the level of equipment/technology, norms and rules, training and verification. Its adaptation to evolution over time through the introduction of the «change management» module, which is based on the constant monitoring of threats of a natural, technical, economic and human nature, analysis of changes in their structure and intensity of impact on the system	Implementation of a set of measures to reduce the vulnerability of the system at the level of equipment/technology, norms and rules, training and verification. Its adaptation to evolution over time through the introduction of the «change management» module, which is based on the constant monitoring of threats of a natural, technical, economic and human nature, analysis of changes in their structure and intensity of impact on the system

The catalog of «Dramatek» developments and the corresponding «Dramatek-scenarios» (chains of structurally and logically connected episodes) should be stored in the aviation safety risk management knowledge base, which will provide the possibility of a systematic approach to it.

5. 3. Application of the nuclear language of situational management to describe a fragment of a dangerous aviation situation based on the frame approach

One of the riskiest stages of the flight is the actual landing of the plane. At the same time, the key aspects of safety at this stage of the flight are maintaining the descent glide path and maintaining the range of permissible landing speed.

The following situation was investigated in our work.

Aircraft B 737-800 flight LH7132 is descending at Nairobi Airport. At the final stage of the flight, pilots evaluate the development of the landing scenario according to two main indicators: the position of the aircraft in relation to the glide path and compliance with the landing speed limits (Fig. 2).

Possible scenarios and actions of the aircraft commander are given in Table 5.

Possible segmentation of aircraft landing scenarios.

Aircraft landing scenarios:

1. The plane is about to land.
2. Analysis of compliance with the gliding position and compliance with the permissible landing speed range.
3. Risk assessment.
4. The plane continues landing.
5. The plane goes on a correction circle.
6. Return to glissade.
7. Return to the permissible speed range.
8. The plane is landing.
9. The plane taxis to the parking lot.

According to [17], one of the types of frames that can be used to represent non-visual knowledge about the world and allows saving memory and perception time is a frame script. In addition, one of the means of formalized presentation of frames-scenarios is the specified AND/OR graph structure. In this representation, the top of the graph corresponds to the title of the frame-script, and the other vertices of the graph, which depict the corresponding actions, correspond to the numbers of scenes and actions of the script.

A fragment of the frame network corresponding to the aircraft landing scenarios is shown in Fig. 3, 4.

The directed edges shown in Fig. 3 reproduce the operational relation. The sequence of transition from state to state of the system is set by vertices, that is, the so-called time order is established. Violation of strict ordering is possible by an alternative transition after vertex 2, when the real situation can transfer the system immediately to situation 4, or the sequence of vertices 2-3-6-2 or 2-3-7-2 can be repeated several times, after which the system can transition either to state 4 or to state 5. Scenarios, on the one hand, are used to update the representation of the situation, and on the other hand, they are naturally reflected in prototype frames, that is, in particular, in four known classic types of frames: technology frames, conflict frames, production frames, and indicator frames. This typification is well-known but far from the only one. The second type of frames (conflicts) is used for the classification of conflict situations, the means of detection, the reasons for their occurrence, and the description of the elimination of conflict situations. Conflict frame is a commonly used term, and, in these studies, the conflict of the situation is interpreted as being in the corresponding risk zones.

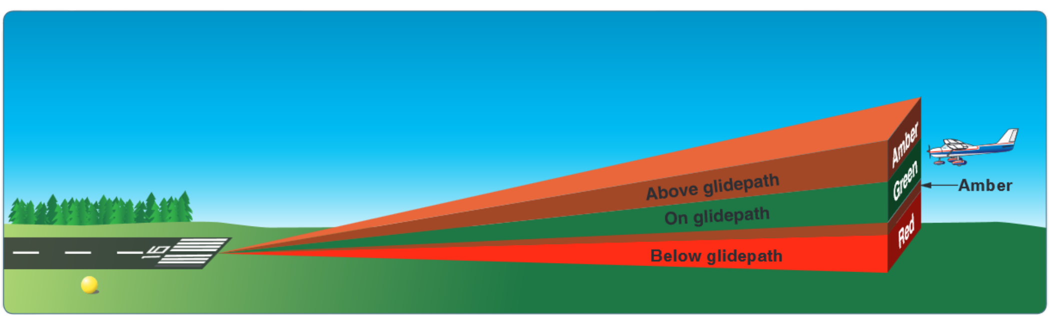

Fig. 2. Visual indicators of descent along the glide path [17]

Table 5

Options for the development of aircraft landing scenarios

Staying at the glissade	Staying under the glissade	Staying over the glissade	Landing speed in the permissible zone	Landing speed below minimum	The landing speed is higher than the maximum	Possible outcome/actions
+	–	–	+	–	–	Positive
–	+	–	+	–	–	The risk of underflying/or returning to the glide path or to the second circle
–	–	+	+	–	–	The risk of leaving the runway/or returning to the glide path, or to the second circle
+	–	–	–	+	–	The risk of underflying/or increasing the speed or returning to the second circle
+	–	–	–	–	+	The risk of leaving the runway/or reducing the speed, or returning to the second circle
–	+	–	–	+	–	Risk of underflying/ we increase the speed and exit to the second circle
–	–	+	–	–	+	Risk of departure from the runway/exit to the second circle

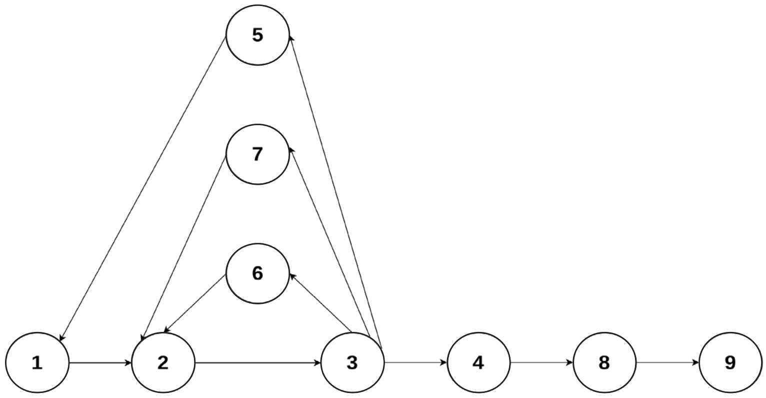

Fig. 3. A fragment of the network of frames that corresponds to the scenario of landing an aircraft

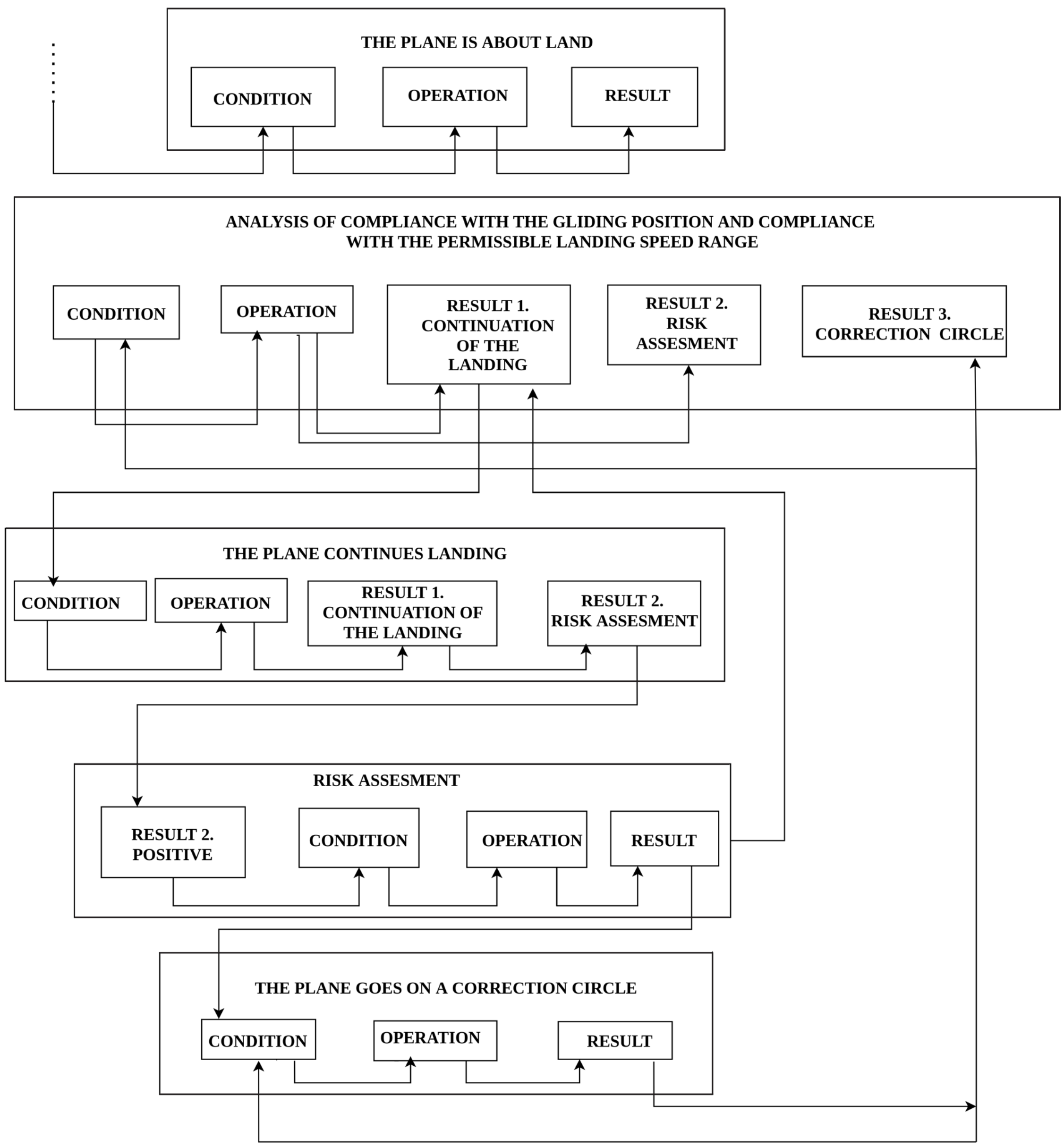

Fig. 4. Structure of risk frames

Vertices 1, 4, 5, 9 are displayed in frames of the type of products, which describe cause-and-effect relationships that contribute to obtaining the final positive situation – the immediate goal of management.

Vertices 2, 3 correspond to conflict frames.

Vertices 6, 7, 8 correspond to indicator frames, in which, in particular, the results of the influence on the control object by the control system are reproduced.

At the same time, the structure of risk frames corresponding to the scenarios of Fig. 3, may take the following form (Fig. 4).

A fragment of the possible result of actions:

– if the aircraft B737-800 performing flight LH732 lands at Nairobi Airport and is on a glideslope, and the landing speed is in the acceptable zone – a situation of acceptable risk;

– if the aircraft B737-800, performing the flight LH732, lands at the Nairobi airport, it is under the glideslope, and the landing speed is in the acceptable zone – a situation of acceptable risk;

– if the aircraft B737-800 performing the flight LH732 lands at the Nairobi airport, it is above the glideslope, and the landing speed is in the acceptable zone – a situation of acceptable risk.

To describe the composition of situations in the language of situational management, a table of used lexical groups was previously compiled.

The list of used lexical groups of MSU: concepts; names; classification relation; actions; quantifiers; modifiers; modalities; estimates for this emergency situation are given in Table 6.

Based on the data in Table 6, a fragment of a dangerous aviation situation with a frame approach using the nuclear language of situation management will take the following form:

$$\begin{pmatrix}\big(\big(\big((VS\cdot\rho\cdot i_1)\cdot d_1(R\cdot\rho\cdot i_1)\big)\cdot d_2(A\cdot\rho\cdot i_3)\big)\times\\ \times\big(\big((VS\cdot\rho\cdot i_1)\cdot d_1(R\cdot\rho\cdot i_2)\big)\cdot r_{30}\cdot G\big)\wedge(PS\cdot r_{44}\cdot D)\big)\end{pmatrix},$$

$$\Rightarrow(S\cdot\rho\cdot B)\cdot\begin{pmatrix}(VS\cdot\rho\cdot i_{1)})\times\\ \times d_1\big((R\cdot\rho\cdot i_2)\cdot r_{41}\cdot G\big)\wedge\\ \wedge(PS\cdot r_{44}\cdot D)\end{pmatrix},$$

$$\Rightarrow(S\cdot\rho\cdot TR)\cdot(VS\cdot\rho\cdot i_{1)})\times$$

$$\times\, d_1\big((R\cdot\rho\cdot i_2)\cdot r_{40}\cdot G\big)\wedge(PS\cdot r_{44}\cdot D),$$

$$\Rightarrow(S\cdot\rho\cdot TR)\cdot(VS\cdot\rho\cdot i_1)\times$$

$$\times\, d_1\big((R\cdot\rho\cdot i_2)\cdot r_{30}\cdot G\big)\cdot(PS\cdot r_{15}\cdot MS),$$

$$\Rightarrow(S\cdot\rho\cdot TR).$$

Table 6

List of used lexical groups

No. of entry	Concept		Name		Classification relation		Action	
	Name	Designation	Name	Designation	Name	Designation	Name	Designation
1	Airship	*VS*	B737-800	i_1	Have a name	ρ	Makes a flight	d_1
2	Flight	*R*	*LH*732	i_2	–	–	Going to land	d_2
3	Airport	*A*	Nairobi	i_3	–	–	On glissade	r_{30}
4	Glissade	*G*			–	–	–	–
5	Landing strip	*PS*	–	–	–	–	–	–
6	Zone	*D*	–	–	–	–	–	–
7	Situation	*S*	–	–	–	–	–	–
8	Minimum	*MS*	–	–	–	–	–	–
9	Risk tolerance	–	Acceptable risk	*B*	–	–	–	–
			Tolerable risk	*TR*	–	–	–	–

Based on the concept of the language of situational management, according to which the objects of situations with them and management procedures are described, the fragment $((VS\cdot\rho\cdot i_1)\cdot d_1(R\cdot\rho\cdot i_1))\cdot d_2(A\cdot\rho\cdot i_3)$ has the following «transcription»:

– [$VS\cdot\rho\cdot i_1$]:[The aircraft has the aircraft name B737-800];
– [d_1]:[makes a flight];
– [$R\cdot\rho\cdot i_1$]:[the flight is named LH732];
– [d_2]:[is landing];
– [$A\cdot\rho\cdot i_3$]: [the airport is named Nairobi].

The nuclear language of situational control is very cumbersome and at first glance very inconvenient for situational description, but it is the most adequate for almost verbatim formalization of the natural language of describing the situation, which corresponds to the system of threats in aviation safety.

6. Discussion of research results of theoretical aspects of situational management of aviation safety risks

The development of risk management tools in the aviation safety system is a priority task under the modern conditions of the development of the industry. In contrast to the results of work [1], the issue of operational risk management of aviation safety during the war and post-war development, taking into account the human factor, was resolved. This makes it possible to qualitatively adjust the strategic scenarios proposed in the work. In order to further develop the results of work [2], approaches are proposed regarding the practical application of technological achievements of risk management in force majeure circumstances and under conditions of uncertainty. In contrast to the results of the works that consider the choice of language in the process of managing safety risks [3, 4], the issue of further selection of appropriate MSU for solving strategic and operational tasks of aviation risk management has been resolved. For the use of a simple nuclear language, the following classic groups are selected: concepts; names; relation; actions; quantifactors; modifiers; modalities; evaluations This will increase the effectiveness of risk management measures under conditions of uncertainty. In contrast to the results of works that consider the negative impact of various aspects of the human factor on aviation safety [5–7], a comprehensive study of aviation risk management tools was conducted. Special attention is paid to operational management of aspects of the human factor in the development of an aviation event using the Dramatek methodology. This makes it possible to minimize the negative impact of human errors and violations in situational safety management. In contrast to the results of works that consider the development of a toolkit of reactive, proactive, and predictive methods of aviation safety management [8–10], it is proposed to use the approaches of compiling reactive, proactive, and predictive methods of aviation safety management, which will make it possible to quickly minimize the influence of dynamic negative factors.

Therefore, this study differs from previous studies in the complex application of situational risk management in the aviation safety system. This provides an opportunity to qualitatively improve the effectiveness of measures to prevent aviation disasters, serious incidents, and incidents in aviation transport. In contrast to the results of works that consider the development of situational management and the theory of frames [11–13], the use of methods of situational management and the theory of frames in solving the problems of aviation risk management is proposed.

The results obtained in studies that consider the application of the theoretical principles of situational risk management in the aviation safety system are explained by the specific features of the situational management system (Fig. 1). According to Fig. 1, the «analyzer» is partially described by the values of the weighting coefficients of probability (Table 1) and the values of the weighting coefficients of degrees of severity (Table 2), as well as by the matrix of indicators of the assessment of aviation safety risks M_{RAI}, based on which the partial formalized description of the «classifier» is Table 3. The linguistic segment of the «extrapolator» is Table 4, which reproduces the development of the drama of the aviation safety risk management episode. An element of the «block of decision-making under uncertainty» is Table 5 (options for the development of scenarios), in particular the column of the indicated table «Possible result/actions». Another element of this block is the structure of riskiness frames (Fig. 4). The signal of «influence on the object» is the description of the actions of the control object carried out in the nuclear language of situational control (Table 6).

Our research is significantly limited for aviation safety risk management. It was envisaged to create only fragments of the application of the «dramatek-scenario» of the aviation safety risk management episode and to create an example of the use of the nuclear language of situational management to describe a fragment of a dangerous aviation situation based on the frame approach. These fragments demonstrate the need for the development of special modern software tools that make it possible to work with data that has a complex internal global and local structure, that is, programming environments capable of interpreting knowledge representations.

Aviation safety is a strategic object, and therefore the specified programming environments must be sufficiently protected from external interference and from internal sensitivities in matters of confidentiality and stability of information.

The development of this research may consist in a more detailed study and analysis of aviation safety risk situations, the methodology of their formal description and the formalization of means of their elimination. Also, the development of this research can be carried out in a more thorough study of «Dramatek» theories and frames.

7. Conclusions

1. The probability weighting coefficients of the risk characteristics were calculated, the weighting coefficients of the degrees of severity were calculated, and a matrix of risk assessment indicators was constructed. The numerical matrix of risk assessment indicators made it possible to formulate the trajectory of risk management with an indication. limit values of risk zones: zone of unacceptable risk; zone of acceptable risk; zone of permissible risk (operational management).

2. The developed «dramatech-scenario» of aviation safety risk management will contribute to minimizing the negative impact of human errors and violations.

Taking into account the experience of readiness for continuous professional development, initiative, and individual abilities of representatives of aviation services generalizes the game-theoretic approach into the theoretical-dramaturgical one. This approach, in particular, involves the division of a rather complex drama into several interconnected episodes of the same structural type. At the same time, a unified perception of the situation is achieved and thus conditions are created for the evolution and appearance of new games. The result is finding a solution that is optimal for all players or proving its non-existence.

3. We have proposed an approach of using the nuclear language of situational management to describe a fragment of a dangerous aviation situation based on the frame approach. The main content of the approach is to use a combination of the following main theories:

– theories of situational management, on the basis of which the model of the management object is described in the nuclear language of situational management;

– frame theory, in which the regulator model is described by means of knowledge representation languages, convenient for organizing computer procedures, where the cumbersomeness of implementation is compensated by increasing the adequacy of aviation safety risk management.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

References

1. Kharazishvili, Y., Kwilinski, A., Bugayko, D., Hryhorak, M., Butorina, V., Yashchyshyna, I. (2022). Strategic Scenarios of the Post-War Recovery of the Aviation Transport Sustainable Development: The Case of Ukraine. Virtual Economics, 5 (3), 7–30. doi: https://doi.org/10.34021/ve.2022.05.03(1)

2. Mendes, N., Geraldo Vidal Vieira, J., Patrícia Mano, A. (2022). Risk management in aviation maintenance: A systematic literature review. Safety Science, 153, 105810. doi: https://doi.org/10.1016/j.ssci.2022.105810
3. Patriarca, R., Di Gravio, G., Cioponea, R., Licu, A. (2019). Safety intelligence: Incremental proactive risk management for holistic aviation safety performance. Safety Science, 118, 551–567. doi: https://doi.org/10.1016/j.ssci.2019.05.040
4. Yang, C., Huang, C. (2023). Natural Language Processing (NLP) in Aviation Safety: Systematic Review of Research and Outlook into the Future. Aerospace, 10 (7), 600. doi: https://doi.org/10.3390/aerospace10070600
5. Bendak, S., Rashid, H. S. J. (2020). Fatigue in aviation: A systematic review of the literature. International Journal of Industrial Ergonomics, 76, 102928. doi: https://doi.org/10.1016/j.ergon.2020.102928
6. Li, C., Sun, R., Pan, X. (2023). Takeoff runway overrun risk assessment in aviation safety based on human pilot behavioral characteristics from real flight data. Safety Science, 158, 105992. doi: https://doi.org/10.1016/j.ssci.2022.105992
7. Wu, Y., Zhang, S., Zhang, X., Lu, Y., Xiong, Z. (2023). Analysis on coupling dynamic effect of human errors in aviation safety. Accident Analysis & Prevention, 192, 107277. doi: https://doi.org/10.1016/j.aap.2023.107277
8. Zhang, X., Mahadevan, S. (2021). Bayesian network modeling of accident investigation reports for aviation safety assessment. Reliability Engineering & System Safety, 209, 107371. doi: https://doi.org/10.1016/j.ress.2020.107371
9. Zhang, X., Mahadevan, S. (2019). Ensemble machine learning models for aviation incident risk prediction. Decision Support Systems, 116, 48–63. doi: https://doi.org/10.1016/j.dss.2018.10.009
10. Hamza, M. H., Polichshuk, R., Lee, H., Parker, P., Campbell, A., Chattopadhyay, A. (2022). Aircraft post-upset flight risk region prediction for aviation safety management. Advanced Engineering Informatics, 54, 101804. doi: https://doi.org/10.1016/j.aei.2022.101804
11. Christensen, O., Goh, S. S. (2021). Explicit construction of frames and pairs of dual frames on locally compact abelian groups. Sampling Theory, Signal Processing, and Data Analysis, 19 (1). doi: https://doi.org/10.1007/s43670-021-00004-4
12. Sanjitha, R., Thankachan, B. (2024). Aggregation operators on multiple sets and its application in decision-making problems. Global and Stochastic Analysis, 11 (1), 81–94.
13. Massit, H., Rossafi, M., Park, C. (2023). Some relations between continuous generalized frames. Afrika Matematika, 35 (1). doi: https://doi.org/10.1007/s13370-023-01157-2
14. Pospelov, D. A. (1991). Situational Control: Theory and Practice. Battelle Memorial Institute, 344.
15. Doc 9859. Safety Management Manual. International Civil Aviation Organization. Available at: https://skybrary.aero/sites/default/files/bookshelf/5863.pdf
16. Leshchynskyi, O. L., Shkolnyi, O. V. (2005). Ekonomichnyi ryzyk ta metody yoho vymiriuvannia. Kyiv: Delta, 112.
17. Visual Glide Slope Indicators. Available at: https://www.cfinotebook.net/notebook/aircraft-operations/terminal/visual-glide-slope-indicators
18. Minsky, M. (1974). A Framework for Representing Knowledge. Available at: https://courses.media.mit.edu/2004spring/mas966/Minsky%201974%20Framework%20for%20knowledge.pdf