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SIMULATED MODEL OF THE FLIGHT SAFETY MANAGEMENT SYSTEM IN GENERAL AVIATION ENTERPRISES OPERATING CORPORATE AND BUSINESS AIRCRAFT

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ABSTRACT

The paper describes a method for predicting aviation events in general aviation enterprises on the basis of a simulated model of the flight safety management system (FSMS) and identification of time series allowing the use of simulated models of the flight safety management system as a tool for studying the logic of the cause-and-effect mechanism of aviation events with the subsequent formation of the list of substantiated flight safety measures for the predicted system performance. The dynamics of the predicted indicators in the field of stable and unstable operation of the simulated flight safety management system is studied. For unstable operation areas, the cause-effect mechanism of the origin and development of aviation events is substantiated and analyzed. The physical meaning of the identification of aviation events by time series is the implementation of the flight safety management system at each phase point of the *unstable operation area, taking into account the logic of the cause-and-effect mechanism of aviation events, thus creating a list of substantiated measures with the required resources in the form of cognitive maps to make managerial decisions to ensure flight safety for the predicted performance of the aviation and technical system.*

Key words: Simulated Model, Flight Safety, Aircraft, Aviation Event, Aviation Enterprise, General Aviation.

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1. INTRODUCTION

The accident rate in general aviation is one of the gravest problems. The number of accidents in general aviation (GA) has not declined over the past decade. On average, 15-17 aviation accidents in a year occur in GA including 8-11 collisions. The number of deaths in general aviation increased significantly as the GA market expanded; for example, in 2006, the number of deaths in GA was 1% of the total number of deaths, and in 2015 this number equaled 30% [1-3].

The problem of accident rate in GA is connected with aviation enterprises that violate the rules of the preparation of aircraft for flights and the rules of flight operations.

In the national practice, home and foreign made aircraft are used in general aviation. The total fleet of national corporate and business aviation aircraft is more than 120 and is represented by airplanes of the type Yak-40, Yak-42, etc.; the foreign fleet includes more than 140 aircraft and is represented by airplanes of the type Embraer 135/140/Legacy, HS 125-700, Falcon, Challenger 604, etc.

The operation of general aviation aircraft is significantly different from the use of commercial aviation aircraft by the regularity of flights and the types of air operations. As a result, aviation specialists, pilots and crews carry out their professional activities in specific conditions of VIP transportation for passengers and groups, such as well-known sports teams, journalists, musicians, etc., recreational flights (recreation, hunting), sanitary flights, etc., and cargo transportation of personal belongings of VIP persons and groups, antiques, etc.

The use of corporate and business general aviation implies personal contact of the aircraft crew with VIP persons and group leaders both in preparation for flights and during the flight, and an increase in waiting time excessing the established norms, which is strictly prohibited by commercial aviation.

According to the conceptual model [4], a simulated model was created (Fig. 1) of an aviation enterprise FSMS for corporate and business general aviation.

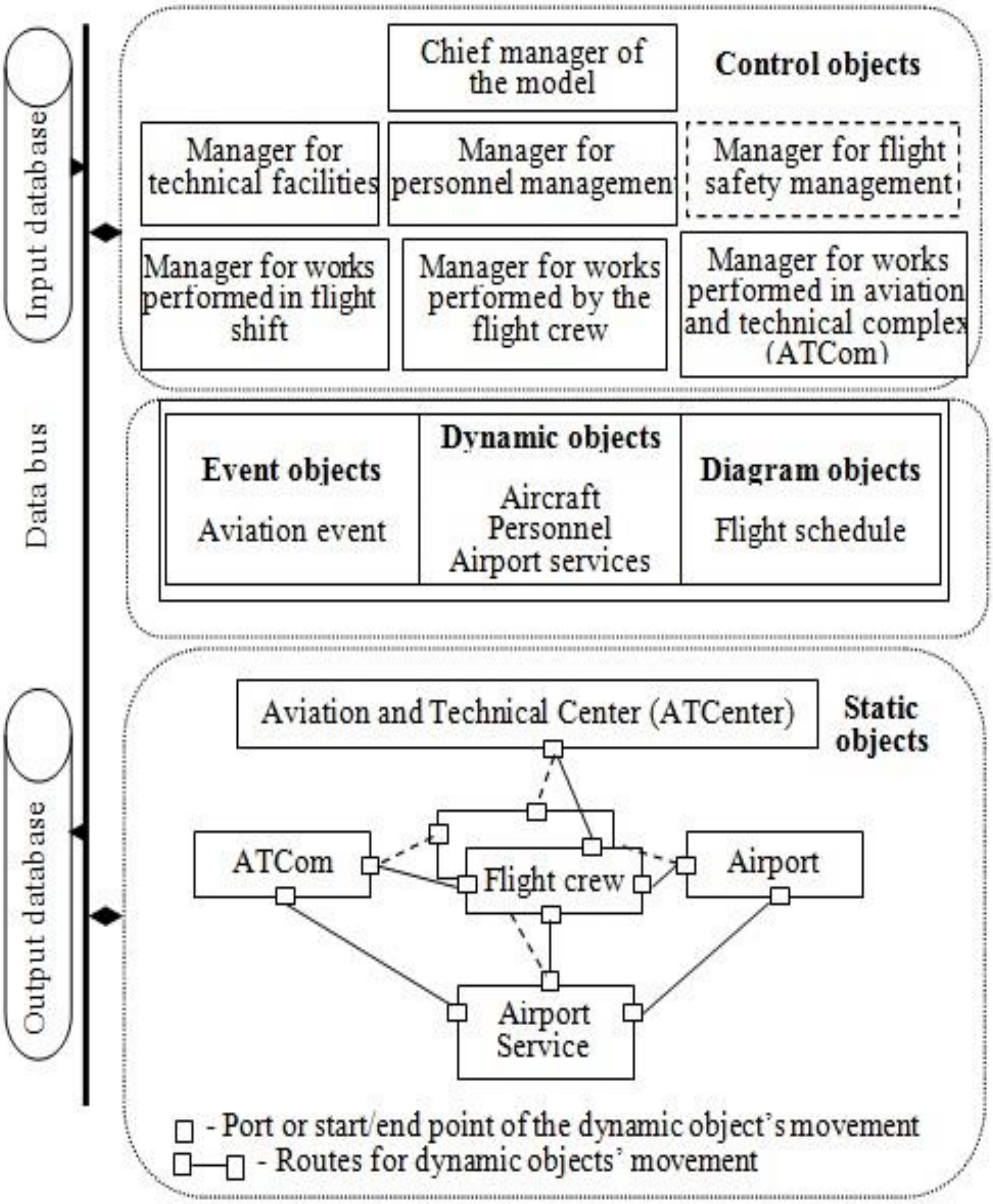

Figure 1 Simulated model of an FSMS in general aviation enterprises operating corporate and business aircraft

To describe the simulated model (SM), the software environment *AL* and *Java* were used. The model contains a database and a knowledge base with subprograms that perform statistical, non-linear dynamic processing of simulation results and predictive estimates.

All SM objects are classified into 5 groups:

- Event objects – objects where predefined actions are performed after triggering (timer) or occurrence of events;
- Control objects – objects containing control algorithms for other objects that can change the features and structure of other objects;
- Static objects – objects from which the model structure is constructed, can be containers of other objects;
- Dynamic objects – objects that move along the model structure between static objects;

- Diagram objects – objects the behavior of which is described in terms of the state-transition diagram.
- Each specialist is a unique object of SM and is classified according to the following features:
- By flight work – ground (specialists of the engineering and technical personnel (ETP)) and airborne (flying) ones;
- By profession – pilots, navigators, flight engineers, specialists in aircraft, engines, aircraft equipment, radio electronic equipment, air traffic control specialists;
- By posts – pilots, engineers, technicians, mechanics, drivers, operators;
- By the nature of participation in the tasks – basic (crew chief, senior aircraft technician), auxiliary (co-pilot, senior aircraft and engines technician), supporting (specialists in national and foreign aviation technical complexes (AT Com) and centers (AT Center) (maintenance and repair such as C-check, D-check, SV (Shop visit), aerodrome service specialists (providing aircraft maintenance and readiness)
- By qualification – airline pilot (and others, according to the Federal Aviation Regulations), masters, classified specialists (1, 2, 3 classes), non-classified specialists;
- By functions performed – heads of subdivisions, deputy chiefs of subdivisions, Heads of groups;
- By belonging to organizational units – specialist of the aviation enterprise, specialist of the aerodrome service, AT Com specialist, AT Center specialist;
- By social status – with low, medium and high wages;
- By individual features – age, length of service, flying hours (general, for a particular type, the nature of flying experience), education (Civil School (Institute), Military School (Institute), Russian Defence Sports and Techniques Organization/ROSTO (Russian Army, Air Force and Navy Volunteer Society/DOSAAF), foreign educational institutions), the average score after the educational institution.

Of the most important methodological significance for the theory and practice of flight safety is aviation event prediction, the ultimate aim of which is to develop measures that can effectively influence the overall flight safety level in general aviation for corporate and business flights.

The investigated problem of predicting aviation events belongs to the sphere of improvement and development of complex anthropocentric systems. Based on the implementation of predictive assessments of flight safety state in the form of a time series, the object of research in this paper is the time series of aviation events (AEs) in general aviation for corporate and business flights [5-7].

2. GOAL AND OBJECTIVES

The aim of the study is to improve the flight safety of general aviation aircraft [8] by ensuring the reliability of predictive safety level assessments in general aviation enterprises in the short, medium and long term.

Proceeding from the goal set, the following interrelated scientific objectives were solved for general aviation enterprises: general analysis of the AE time series was performed; a method for identification of the AE time series was developed on the basis of classical statistical and non-linear dynamic methods; an input data system with a friendly interface was developed; logical, semantic and mathematical algorithms for the flight safety management system (FSMS) operation [9] were developed in the form of a lexicographic order and programs in the generated knowledge base; a simulated FSMS model was created; a system of FSMS indicators was substantiated and formed, which makes it possible to manage the FSMS state and identify the

AE cause-and-effect mechanism; an FSMS monitoring system was developed; a computational experiment was performed to obtain predictive estimates of the dynamics of the simulated SMS indicators and to identify the main factors affecting the flight safety level.

3. METHODS & MATERIALS

When analyzing situations under conditions of behavioral uncertainty, several principles for constructing the choice function [10-13] were used; in this case the main principle is the principle of guaranteed result based on the hypothesis of extremely adverse circumstances for the person making the decision (PMD). The following principles: max-min (Wald), min-max (Savage) were used. The best strategy *a** is determined by the following rule:

$$a^*: \min_a \max_s [\max_a y(a,s) - y(a,s)] \quad (1)$$

Where *y(a, s)* is the control function, *a* and *s* are the control parameters.

The principles of Wald and Savage are categorical in the sense that one of them focuses only on the worst-case scenario, and the other one – on maximum losses. The Hurwitz principle is characterized by some balance between the worst and the best choice for strategy. According to the Hurwitz principle, the best strategy is a strategy that leads to the greatest value of the linear convolution of the worst and best:

$$a^*: \max_a [\gamma \cdot \min_s y(a,s) + (1-\gamma) \cdot \max_s y(a,s)]. \quad (2)$$

Where γ is the linearity co efficient.

The Hurwitz principle may not identify explicitly differently preferred alternatives because for each of them it assigns an estimate that is a linear combination of the worst and best choice for this alternative. To eliminate this deficiency, the Hurwitz principle is modified in such a way that intermediate results are also included in it when evaluating the alternative. Such a modification makes it possible to take into account the variety of psychophysical characteristics of experts performing the evaluation of alternatives [14-18].

In the most important system "Crew-Aircraft", technical and personal aspects are equal in number and weight of system factors. The aircraft crew interacting with information displaying means, accidental disturbances from the part of entities, and means of influence is an integrated element "crew - means of activity" (Fig. 2) [19-23, 3].

In the psychology of flight work, a special type of stress is investigated: the stress in flight, due to the peculiarities of flight work and the flying qualities of pilots, navigators, and in some cases radio operators, as well as engineering and technical personnel (flight engineers, flight technicians, etc.) [5].

The flight crew of corporate and business aviation have to work in conditions of: a severe time deficit; the most loaded sensory field; monotony (sameness of the situation); maximum vigilance and constant readiness to engage immediately and rapidly in complex sensorimotor activity; remnant and functional dependence on the composition of the crew (ambiguity of the pilot's response to special flight situations depending on the composition of the crew); emotional stress of responsibility for VIP passengers.

The problem of ensuring the reliability of the flight safety level prediction in general corporate and business aviation refers to the problem of improving and developing systems. These are weakly structured problems, the solution of which is the object of investigation of system analysis and synthesis.

The analysis of the problem description defined its formalized form:

$$M: \quad D_n = \arg\max_{g \in G} \{K_g \mid S^*(BZ(Q_K); BD(Z_K))\}, \tag{3}$$

where D_n is the prediction reliability (certainty); $\{K_g\}_G$ is a set of tasks to be solved in the flight safety management system; $S^*(\ )$ is the amount of information in the database $BD(Z_K)$ and the availability of algorithms for solving problems contained in the knowledge base $BZ(Q_K)$; Q_K is the composition, i.e., qualitative and quantitative parameters of the flight safety management system elements; Z_K is the amount of logical information, algorithms and programs that define the rules for the flight safety management system operation $Z_K \geq Z_{norm}$; Z_{norm} is the number of logical and semantic algorithms that define the rules for the flight safety management system operation, and requirements set out in the FARs, GOST, EN/AS, ICAO documents, ETOPS and qualification requirements [24].

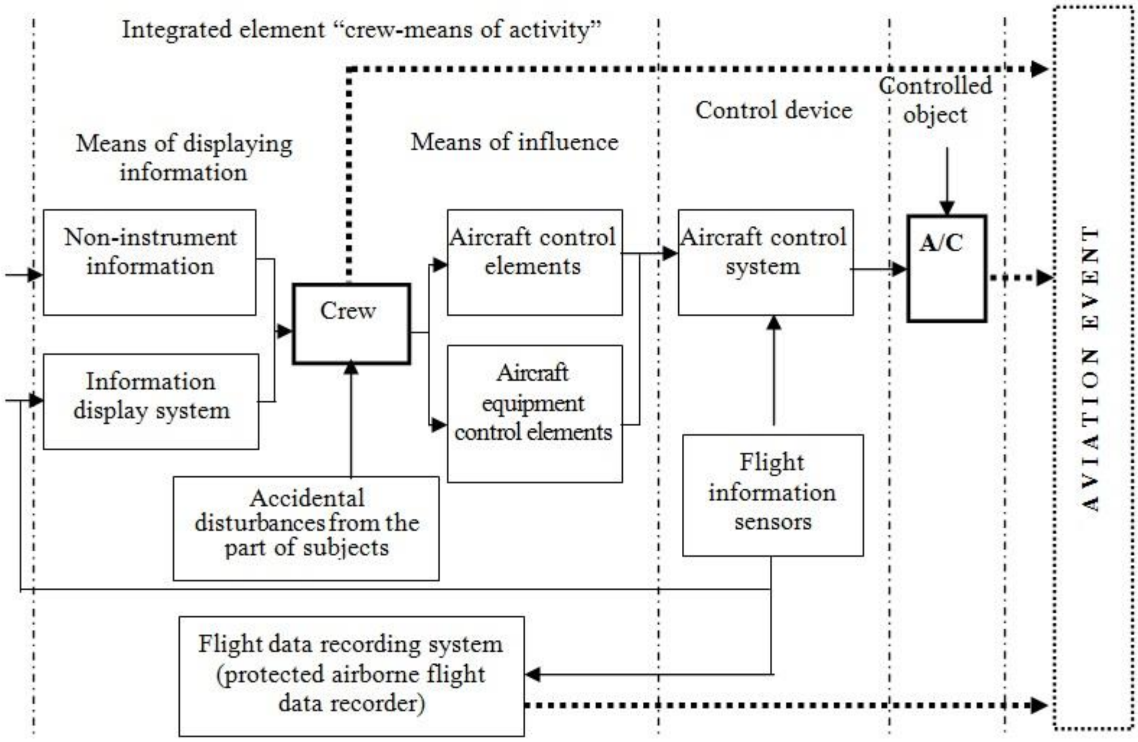

Figure 2 "Crew-Aircraft" system model for general corporate and business aviation

In this version of the SM, the following individual features and environmental factors are supported: qualifications, intensity and productivity of work, remnant and functional relationships. Specific and non-specific intensity of work relative to the flight is considered by the indicator of the intensity of the work process in a scale of 0-100% [25].

The validity of the model was provided using the Wilcoxon test (according to the hypothesis that each value obtained in the SM has the same distribution as the corresponding statistical data) used for small samples. According to the Wilcoxon test with a significance level of less than 0.05, the SM is adequate to the real-world process.

The simulated model of the flight safety management system in a general aviation enterprise is a tool for studying the logic of the cause-and-effect mechanism of the occurrence of aviation events, with the subsequent formation of a list of justified measures with the required resources in the form of cognitive maps for making managerial decisions to ensure flight safety for the predicted performance of the system operation.

To assess the effectiveness of the FSMS operation in an aviation enterprise of general corporate and business aviation, the simulated FSMS is presented as an organizational structure. Then the FSMS emission can be represented as a binary tuple:

FSMS = {Objectives, Resources}. (4)

Using the system methodology, a binary decomposition is performed for the set *Objectives* that is part of the expression (1)

Objectives={$O_{external}$, $O_{internal}$ }, (5)

where $O_{external}$ is a set of goals reflecting the global objectives of the FSMS – ensuring the required level of flight safety;

$O_{internal}$ is a set of goals set to improve the organization of the FSMS itself.

The set *Resources* includes the following components, which together represent the possibility of achieving the FSMS objectives:

Resources = {TechR, TechnicR, HR, FR, MR, OR, IR, CSR}, (6)

Where *TechP* is technological resources, *TechnicR* – technical, *HR* – human, *FR* – financial, *MR* - material, *OR* – organizational, *IR* - informational, *CSR* – Control System Resources.

In FSMS, some types of resources act as nodal elements in the organizational structure of interactions (human resources as a social component and technical resources as a material component), other types of resources are mediating factors in streams of events. Information resources are shown by arrows – directed towards FSMS resources, and the organizational resource, which is the FSMS organizational structure formed by an ordered set of units and functional services, as well as the structure-forming documents is the space in which FSMS resources interact.

In this way, such types of resources as technological, financial and material play the role of intermediate linking nodes, as they characterize the way of connecting human and technical resources.

The human resource includes aviation personnel, i.e., a vast number of specialists ordered by structural units, functional duties, services, etc.

The technical resource represents a variety of means of aircraft operation and maintenance, tools and control equipment.

The technological resource provides the main FSMS activity and includes:

- A number of technological processes of operation;
- A set of indicators of personnel qualifications reflecting the level of technological culture and compliance with the conditions and requirements of the technological processes of aircraft preparation for flights.

The material resource represents a number of FSMS facilities:

- Spare parts and materials including group kits, technical kits and spare parts in bulk;
- Aviation and technical equipment;
- Movable and immovable assets.

The financial resource is a set of elements and a set of technological processes of the FSMS as a financial environment.

The control system resource is a set of processes for the management of human and technical resources (personnel work, etc.).

To make it possible to identify the cause-and-effect mechanism of the AE occurrence and some FSMS states, the indicators are selected that characterize the effectiveness of the FSMS operation and reflecting the relationships between the FSMS elements, the internal processes and the environment, both external and internal. These requirements are most fully met by such "system" indicators as [26]:

- Readiness characterizing the possibility of the system to start successfully fulfilling the tasks;
- Flight safety characterizing the protection of the system from internal and external hazards. Flight safety is an integral form of the protection of the main element of the "Crew-Aircraft" system that performs the assigned task;
- The economic indicator characterizing the economic capabilities of the system for ensuring readiness and flight safety.

Thus, we have a system of indicators consisting of 2 groups: a group of "system" indicators including subgroups for indicators of readiness, flight safety, economic indicators, and a group of "particular" indicators consisting of subgroups for indicators that characterize some type of FSMS resources. Thus, the system indicators are designed to characterize the effectiveness of the entire SMS operation, and the particular indicators are designed to characterize the individual FSMS elements and to identify the cause-and-effect mechanism for the AE occurrence, as well as the cause of an FSMS state.

There are many approaches for assessing the values of the selected system of indicators. The first one makes it possible to compare them with:

- Indicators of another aviation enterprise's FSMS;
- Absolute indicators according to standards;
- The results of the FSMS operation in dynamics (compare data over certain periods).

The second approach is based on expert assessments of indicators. However, the above study shows that these traditional approaches do not fully reflect the results of the SMS operation. The system of indicators is considered outside their links, which impairs the evaluation of its activities and prevents forming an objective general evaluation in the form of a single number. As a result of this analysis, it is possible to determine what the FSMS has achieved and identify some negative trends, but it is not possible to identify the most problematic bottlenecks in the FSMS operation. In the long run, all this reduces the practical value of such an evaluation of the system of indicators.

It becomes obvious that a mechanism is needed that would allow an objective evaluation of the effectiveness of the FSMS operation and reveal bottlenecks in its operation. Such a mechanism was developed and published in works by Prof. Syroyezhin [27].

The methodological basis of this mechanism is the dynamic normal theory. The dynamic normal is a set of indicators ranged in terms of growth rates so that maintaining this order over a long time interval ensures the best mode of operation of the system under consideration. The dynamic normal is a model of the reference mode of operation of the system under consideration.

An inherent advantage of this approach to assessing the effectiveness of the FSMS operation is the capability to work with interrelated indicators and the possibility of expressing by a number of special features of the FSMS that are not inherent in its subsystems and units (the emergent property of the FSMS). The latter provides an invaluable methodological contribution to the development of system analysis, since a property of the FSMS, which is not a property in the form of a sum of the properties of its components, has not been evaluated before, and the researchers have only ascertained its existence.

The evaluation quality depends, first of all, on the composition of the indicators included in the dynamic normal, which, in the opinion of the authors [26, 27], must satisfy certain requirements:

- The list of indicators should reflect the integral nature of the activity of the system under study;
- The indicators should be available from existing reports, and have a single observation period;
- The indicators included in the dynamic normal for the evaluation of the system effectiveness diagnostics should not be derived but primary;

The number of analyzed indicators should not exceed 12.

The selected system indicators satisfy all the points of the requirement. The ordering of indicators into the dynamic normal, as a rule, should be performed on the basis of a qualitative analysis of their movement using expert methods, in which each expert establishes an order that corresponds to their idea of the regulatory mode of the system operation. Such a standard built on the rank ordering of a finite set of indicators characterizes the effective mode of the system operation.

The order of the indicators in the model of the reference FSMS operation mode is determined on the basis of the strategy of the state or an agency with respect to these indicators. So, if flight safety is a priority, the model of the reference FSMS operation mode can be represented as follows:

- Indicator "Flight safety" – rank 1,
- Indicator "Economics" – rank 2,
- Indicator "Readiness" – rank 3.

On the contrary, if economics is a priority, then in the model of the reference FSMS operation mode this indicator gets the normative rank equal to one. All subsequent operation modes are compared to the chosen model of the reference operation mode and evaluated against proximity to it. Particular attention is paid to estimates of deviations and inversions. They must be non-equivalent, thus allowing a different interpretation of the results of the system operation.

The mathematical study of variation in the proximity of rank orderings [27] showed that the Spearman's (by deviations) and Kendall's (by inversions) rank correlation coefficients correspond to the content features of the required estimates. Both coefficients give an estimate of the proximity of one ranking series to another taken as a reference, in the interval from +1 to -1. A score of +1 is obtained when the compared series is in line with the normative one; and -1 – in case of the complete mismatch (one row is inverted in relation to the other). The selectivity of the estimates increases at the ends of the interval. Let us consider the estimation of the proximity of rank orderings for the efficiency indicators by deviations. In accordance with the definition of the essence of the final effectiveness, it is necessary to provide a unified estimation of the effectiveness of the system on the basis of two estimates of the correlations by deviations and inversions. Such an assessment must comply with the following requirements:

- The effectiveness of the system operation should be evaluated in the range from 0 to 1;
- The selectivity of the effectiveness estimates in the positive correlation region should be higher than that in the negative region;
- The effectiveness function must be non-decreasing on the determination interval.

These requirements are met by the dependence of a unified estimation of the studied system effectiveness:

$$E = \frac{(1+\gamma)\cdot(1+\eta)}{4}, \quad (7)$$

Where γ is a correlation estimate characterizing the proximity of two series by deviations, η is a correlation estimate characterizing the proximity of two series by inversions.

At present, the variety of problems solved by monitoring has led to the emergence of many various types of systems that differ in the principles of construction and the rules for obtaining and processing information embedded in them. In this regard, the developed FSMS monitoring system is identified by its place in the existing classification of monitoring systems.

Based on the classification [28], the developed monitoring system (MS) can be identified by the following features:

- By the type of stored data the developed MS belongs to factual MSs, since the storage and processing of data is carried out in the form of structured numbers and texts;
- Due to the fact that the developed MS involves participation of both human and technical means in the information processing mechanism (with the main role in performing monotonous data processing operations assigned to the computer), by the degree of automation the developed MS belongs to automated MSs;
- By the nature of data processing the developed MS belongs to information decision MSs, since in addition to information entering, organizing, storing and outputting processes, it also processes information following the given algorithms;
- By the use of the output information the developed MS belongs to advisory systems, as it generates information that is taken into account by human operators and is considered in the formation of managerial decisions, and does not initiate specific actions;
- By the scope of application the developed MS belongs to special MSs Due to the fact that it was developed to solve specific problems in the aviation sphere.

Table 1 Data used for simulation

Indicator	**Duration, min.**	**Periodicity**	**Probability of failure and malfunction detection**
Servicing in the flight shift			
Transit check		Prior each flight	0.075
Daily Check		Every day	0.132
Works in ATComm			
Weekly Check	210	Once per week	0,216
A-check	every 500 flight hours		
A1	240		0,296
A2	300		0,296
A3	330		0,296
A4	360		0,296
B-check	320	every 3 months	0,316
ATCenter (foreign company)			
C-check (C1, C2, C4, C6 and C8)	20160 (2 weeks)	every 15 - 20 months or 4 000 flight hours	0,412
D-check	50400 (35 days)	every 12 years	0,456
SV	10080 (1 week)	every 12000 flight hours of the main engine	0,462

Thus, the classification described makes it possible to classify the developed FSMS MS into a class of automated expert systems. The FSMS MS applications were developed and verified in accordance with the qualification requirements of KT-178V and GOST Z ISO/IEC 12207-99, 9126-93, GOST 28195-89, GOST 19.503-79 ... 19.506-79.

To conduct computational experiments, a general corporate and business aviation enterprise was taken that consisted of two flight crews operating aircrafts: EMBRAER 135 BJ, Gulfstream-550, Boing-737 BJ, BAE-125, Global Express.

Each aircraft has its own unique features: aircraft type, flight hours since placed in service, number of departures since placed in service, assigned indicators.

For these aircraft, the following forms of maintenance are provided: Transit check, Daily Check, Weekly Check, A-check, B-check, C-check, D-check, SV, etc. according to Table 1, and types of flights according to Table 2.

To calculate the effectiveness of the FSMS operation, let us arrange and introduce the correspondence to the indicators of the dynamic normal (Table 3).

A sustainable FSMS state is a state in which external or internal destabilizing factors cannot bring the system out of a stable or quasi-stable state.

In order to approach this FSMS state, it is necessary to provide a control input of the required magnitude during the simulation at the required time. To do this, the following options are set before starting simulation:

- Automatic allocation of aviation personnel in case of their dismissal and sanitary losses, aircraft in case of destruction after accidents and collisions, ground maintenance facilities in case of their disposal (or hull loss) in the required amount;
- Automatic allocation of required financial resources for the organization of flights and work in the ATCom and ATCenter.

Table 2 Initial data used in the flight schedule planning

Flight type	**Flight performing, %**			
	Airline pilot PF	**Airline pilot PNF**	**Commercial aviation pilot PF**	**Commercial aviation pilot PNF**
Flight on a scheduled route to a foreign airport	25	20	18	19
Flight on a scheduled route to a domestic airport	12	16	13	17
Flight on a non-scheduled route to a foreign airport	18	15	14	16
Flight on a non-scheduled route to a domestic airport	12	13	16	12
Long flights on scheduled routes to foreign airports	8	9	8	8
Long flights on scheduled routes to domestic airports	5	7	8	7
Long flights on non-scheduled (mixed) routes to foreign airports	14	12	15	13
Long flights on non-scheduled (mixed) routes to domestic airports	5	6	7	7
Flight on a non-scheduled route to a foreign private airport	1	2	1	1

Table 3 Model of a reference FSMS operation mode

Feature	Indicator	Normative rank	Value
Flight safety	Number of aircraft	1	9
Economics	Net profit	2	27 million rubles (deflation 1,.056)
Readiness	Readiness coefficient	3	0.95

It should be noted that the advantage of running the SM with such a set of options will be the understanding of the needs of the simulated FSMS in human and technical resources over the time interval of the simulation. In simulation modeling, the study of the reaction of a simulated system over time with the gradual introduction of a control input was of research interest, which is adequate to the process of real-world operation.

With limited human resources, the FSMS becomes unstable over time, which results in extremely difficult prediction of the FSMS development, especially in the long term. Therefore, the task is to analyze the behavior of the simulated FSMS in an unstable state. At the same time, of considerable interest is the analysis of the FSMS operation in a complex state:

- The first two years, the system receives all the required resources at the required time;
- The following five years, the system does not receive any required resource;
- The next three years, the system demands for resources are satisfied by 20 ... 30% of the required amount;
- The final five years, the system receives the required resources in the required quantity.

The results of modeling the process of functioning for a general aviation enterprise over 15 years in the interval (2010, 2025) with five simulation runs of the model showed that the efficiency graph fluctuates strongly from year to year, and the simulated FSMS transits from the normal mode to complete disorganization and vice versa sharply, resulting in the efficiency curve that acquires a saw-edged form. The dependency analysis does not answer the question of why the simulated FSMS behaves in such an ambiguous way, even with continuous and timely provision with the required resources.

At the same time, the system indicators reveal the following important points:

1. Absence of directly proportional interdependence of system indicators: if the readiness coefficient of the aviation enterprise is minimal or maximum, then the same behavior and the number of aircraft should be expected. But the increase in the readiness coefficient is mainly due to the increase in the number of flight hours caused by the increase in the number of serviceable aircraft and, as a consequence, the increase in the number of aircraft should be expected. However, such dependencies are not observed throughout the simulation time.
2. Analysis of the absolute values of system indicators shows that in 2017 the readiness coefficient of the aviation enterprise is 0.95, the number of aircraft is 15, and the net profit is 35.7 million rubles. With these values, the FSMS effectiveness indicator is maximal.

4. RESULTS AND DISCUSSIONS

From the analysis of the computational experiment results obtained with the simulated model, the following positions can be derived:

- When the simulated FSMS is in a stable state, even with the constant and timely provision with necessary resources, unstable and sometimes ambiguous operation of both the entire FSMS and the elements of its components is observed. Therefore, when performing the prediction analysis, it is necessary to take into account the features under study, especially those with predicted values exceeding the limits of their admissible values;

- Every point that determines the dynamics of a system indicator is integrative and requires constant refinement in particular indicators;
- When evaluating the FSMS effectiveness, it is important not only to fix any deviation of the obtained result from the planned result, but also to identify the reasons that led to this deviation. Each effective mode of the FSMS operation should be specified.
- In connection with the foregoing, it seems reasonable to clarify the definition of "prediction" for complex anthropocentric systems for which the content definition is not known.

Based on the analysis of the aircraft number dynamics performed by the flight crew of the aviation enterprise (Figure 3), it can be concluded that the reliability of the prediction for complex anthropocentric systems is determined not by the proximity of the experimental dependence to its theoretical analog built, as a rule, according to statistical data, but by the stability property of the system. Therefore, it is necessary to create a methodology for identifying prediction activities with the required flight safety resources, namely:

- At the first stage of the methodology, the requirements for the reliability of the prediction are justified, the class of the predicted system is determined, and the prediction conditions for the FSMS operation are analyzed for the planned perspective of the prediction;
- At the second stage, the task of predictive research is formulated. Further, within the framework of the formulated task, a pre-prediction analysis is performed by means of statistical and non-linear dynamic methods, identify the system under study and its complexity, and form the paradigm of further prediction research;
- At the third stage, a computer experiment is planned and performed on the basis of the simulated model of the FSMS operation of the aviation enterprise under study. To this end, database formats are filled with information that describes human, technical, technological, organizational and other types of resources. The knowledge base is filled with logical and semantic constructions that characterize the entire regulatory base for ensuring flight and technical operation of the aircraft. Graphical applications are configured according to the requirements of the computational experiment plan;
- To perform the computational experiment, the following parameters are set: the number of model runs, the duration of the predictive simulation, the control logic of the flight and technical operations of the aircraft, and the system of predicted indicators is formed.

Based on the study of the dynamics of the predicted indicators, the areas of stable and unstable operation of the simulated FSMS were identified. For the area of unstable operation, the cause-and-effect mechanism of the AE occurrence and development was substantiated and analyzed.

The physical meaning of this procedure is that for each phase point of the FSMS implementation in the area of unstable operation, taking into account the studied logic of the cause-and-effect mechanism of the AE occurrence, a list of justified activities must be formed with the required resources in the form of cognitive maps for making managerial decisions to ensure flight safety for predicted performance of the system operation.

In assessing the reliability of the constructed simulated model of the flight safety management system, the reproducibility of the developed simulated model was revealed in various practical experimental and operational conditions, and a qualitative coincidence was established for the authors' research results set forth in this paper with the results presented in other authors' works presented in [24-28]**.**

5. CONCLUSIONS

1. The flight safety level should be predicted according to the system of indicators, which fully reflects the operation of the FSMS identifying the cause-and-effect mechanism of the AE occurrence and acting as an indicator when the system's state becomes unstable.
2. In order to select and substantiate the system of FSMS indicators, the FSMS functions presented in the form of an organizational structure were decomposed into Objectives and Resources. The results of the decomposition made it possible to form a system of indicators consisting of 2 groups:

- A group of "system" indicators including subgroups of readiness, flight safety and economic indicators;
- A group of "particular" indicators consisting of subgroups of indicators that characterize the resource type of the simulated FSMS.

The system indicators are designed to characterize the effectiveness of the entire FSMS, while particular indicators – to characterize individual elements of the FSMS, to identify the cause-and-effect mechanism of the AE occurrence, and to identify the cause of the FSMS state.

3. The study of the dynamics of the FSMS operation in its stable state made it possible to draw the following conclusions:

- With the constant and timely provision of the FSMS with the necessary resources, unstable and sometimes ambiguous operation of both the entire system and its components is observed. Therefore, when performing the prediction analysis, it is necessary to take into account the features being investigated, especially those with predicted values exceeding the limits of their admissible values;
- The predictive estimate, which determines the dynamics of the system indicator, is so integrative that it requires constant refinement of its semantic load in particular indicators;

When evaluating the effectiveness of the FSMS operation, it is important not only to fix any deviation of the obtained result from the planned result, but also to identify the reasons that led to this deviation. Each effective mode of the FSMS operation should be specified.

4. The study of the dynamics of the FSMS operation made it possible to establish the following:

- Over time, each implementation of the simulated FSMS becomes unique, as well as its resources and their features;
- The maximum response of the FSMS to the long-term and timely input of all required resources, as well as their total absence, after a modeled unstable state, occurs not immediately, but gradually; the duration depends on the system state after leaving the unstable state;
- Under the conditions of a modeled unstable state, the FSMS continues to function satisfactorily. In connection with this, it becomes extremely important to identify and reveal the physical meaning of the insignificant resource that is necessary to ensure the satisfactory operation of the FSMS in a negative prediction environment.

5. A study of the time series of aviation events in general corporate and business aviation enterprises made it possible to prove that the reliability of the prediction is determined not by the proximity of the experimental dependence to its theoretical analog built, as a rule, according to statistical data, but by the FSMS stability.

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