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RISK ASSESSMENT OF CONTROL AND DECISION-MAKING IN THE AIRCRAFT CONTROL SYSTEM

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ABSTRACT

The aim of the article is to develop a methodology for quantitative assessment of the risks of control and decision-making in the control system of complex objects using the example of aircraft. Manned and unmanned vehicles are considered as aircraft. The risk is presented in the work as a complex multifactorial qualitative phenomenon of a stochastic nature. For quantitative risk assessment, formal mathematical and simulation models are proposed. The process of control and decision making is studied as a complex stochastic-programmable system in the conditions of digital transformation of the internal and external environment. Under the external environment, the aviation industry is represented, and under the internal environment, the aviation enterprise. The quantitative level of control risks, conceptually and in practice, is proposed to be assessed by the digital maturity of the stages of the life cycle of control agents: design, production, and operation.

The general approach and tasks of studying the processes of risk formation in the management of aircraft are presented systematically in three digital conceptual contexts. In the volume of the general context, the concept of the digital transformation of the aviation industry is explored. At the second conceptual level, the problem is considered on the example of an aviation enterprise. At the third system level, the most dynamically developing digital technologies in practice, such as "Maintenance of aviation equipment" and "Components of robotics and sensors" are explored. The unmanned aerial vehicle is presented as a robotic complex. In these structural and functional technologies of digital transformation, the most promising and significant digital components are "Staff "; "Models"; "Infrastructure and tools"; "Processes and Products"; "Data". The least secure system link in the exchange of information between an aircraft and the external environment is a radio channel, which is proposed to be replaced by VLC technology in the face of external cyber threats. The formalization of the process of quantitative assessment of the level of digital maturity of an aviation enterprise and the practiced control system in the study is based on a multi-approach methodology using sections of probability theory, mathematical statistics, simulation modeling, and the method of expert assessments.

Keywords: *Aviation Industry, Digital Transformation, Technology Model, Criterion Probability, Imitation Maturity Level.*

1. INTRODUCTION

The rapid development of digital technologies is currently radically changing all, without exception, sectors of the economy and the social sphere. There is a dominant trend of shifting business interests to the digital environment, which significantly reduces transaction costs and expands the scope of economic activity. The main drawback of the early stages of digitalization was that the tasks of digital projects were of a local “point character”, and the terms for the full integration of automated processes into a single management composition were not considered at all, and from this it followed that decision-making was ultimately based on intuition and experience responsible, and not on objective premises. In the professional IT environment and the environment of mass use of information, such concepts as “digitalization”, “digital maturity” were widely used, and relatively recently the phrase “digital transformation” came into use [1,2, 3].

From the point of view of specialists, the key features of "digital transformation" that distinguish it from the concept of "digitalization" are the integration of platforms, the transition from quantity to quality, the solution of complex systemic problems in all socio-economic environments without exception. Industry-specific digital transformation is present in all business processes, generating new information links and benefits. Until recently, it was believed that digital transformation is the local introduction of digital technologies for the computerization of individual services in order to increase the productivity of information documented procedures. But pretty soon the realization came that digital transformation is the organization of business processes in such a way that new opportunities appear to successfully compete in an integrated digital world [4,5,6].

Currently, IT projects are taking on the role of revolutionary tools in business processes, where the main thing is not the digital object itself, for example, an aircraft, airport, digital railway, digital train, wagon, delivery, but a digital process. Quality standards have also been transformed, which, in line with system dynamics, have officially become known as process standards. There are hypotheses that the digital process should be transformed into digital augmented reality, integrating supply, marketing, design, operation, disposal, i.e., cover all stages of the life cycle of an object. The definition of the system was transformed - from the pre-existing "system is a set of interrelated elements united by a common goal", a new one was legalized - "a system is a set of interrelated processes united by a common goal". An object is a process or a phenomenon.

Digital technologies based on Smart began to be widely introduced into business processes. For a comparative analysis and assessment of the current level and measurement of the dynamics of digitalization, there was a need for an integral criterion. As a similar criterion, the “Level of Digital Maturity” was proposed [7,8,9]. To implement projects to increase digital maturity, the following systemic assessments were used: current digital maturity; desired level of digital maturity; an action plan to achieve the target level of digital maturity. The literature analysis showed that the leaders of digital transformation are: SAP, Saber, Inform, Lufthansa Systems, IBM, Oracle, Cisco, Microsoft, Celonis. Among industries, one of the leaders in the digital transformation of business processes is the aviation industry [10]. The aviation industry faces such priority tasks of digital transformation of business processes as: creation and maintenance of modern Internet portals and mobile applications for airlines and airports; risk management platform; technologies for increasing the conversion of sales of tickets, goods and services, personalization of marketing campaigns to increase loyalty and quality of passenger service; optimization of costs for repair and maintenance of the aircraft fleet, efficient planning of airports and ground services.

2. LITERATURE REVIEW

General principles and criteria for digital transformation. This analytical material discusses the issues of assessing the current state and potential of the industry and enterprise in the digital transformation system. The criterion for assessing the level of digital transformation of systems and processes in many publications is proposed - digital maturity. Digital maturity assessment is a systematic multilevel study of an organizational and technical object, which aims to assess its current state and growth potential, identify development directions and develop an individual digital transformation strategy [11,12,13].

The most important integrating factor and tool in practice in digital transformation technologies has become technology - Big Data [14,15]. Among specialists, it is believed that Big Data is the most rapidly developing technology for identifying implicit hidden required knowledge in raw data [16]. These technologies involve working with information of a huge volume from different sources and a variety of functional composition, format and quality. The information is a monitoring product and is constantly updated.

Cloud computing technology. Recently, the Cloud Computing technology has been rapidly developing and being used [17]. Cloud computing is a form of providing computing and network resources, huge data storages and other IT resources on the Internet, which are provided for a fee. Cloud computing offers a service as an online service (cloud computing) for the remote use of computer resources. To speed up access to cloud resources, new so-called "Fog Computing" has appeared - this is the restructuring of cloud computing technology, like distributed processing [18]. This technological solution is a structural intermediary (interface) between the levels of data processing, i.e., between the user and the "cloud". Then, naturally, the data processing speed increases and the user's computing resources are saved, as well as delays are reduced. But, at the same time, the question arises, how many "distance fogs" are needed, and how to integrate them when working in one project. There are also a number of other questions in detail.

The use of new technology creates new problems and ways to solve them. So the work [19], which is of a review nature, the author explores experimentally the effectiveness of cloud computing in nine qualitative and quantitative indicators. In the current situation, providers are trying to evenly distribute the load between servers. The author offers a range of solutions to ensure user satisfaction, as well as improve system efficiency by optimally utilizing virtual machine resources, improving data center response time, and improving overall performance. The task is multi-criteria and difficult to formalize. As a rule, in such tasks and accepted efficiency criteria (in this case, these are time, productivity, energy consumption, costs), it is difficult to find a balance and simultaneous improvement of all indicators.

In [20], the problem of increasing efficiency is also solved by optimization. This problem can be attributed to a particular case of parallelization of calculations. The work "optimizes the execution of tasks in a secure cloud environment." The authors believe that the lower the power consumption, the higher the overall performance of the system. What does the author mean by system performance in this case? If system performance is measured by the total amount of information processed, then specific performance is the amount of information per machine. If the problem is how many machines need to be turned off, then this is queuing theory. The statement that the less the workload of the machines, the higher the productivity (of what?) is controversial.

One of the most important, and even everyday tasks, both in the life of an individual entity and the life cycle of an economic entity, is forecasting the future. This function is implemented by two methods: the method of expert analysis, and formal methods involving computer technology. Mathematical and algorithmic tools are used to formalize forecasting processes. American meteorologist Edward Lorenz, proved by the extreme sensitivity of formal methods to initial data, which plays a huge role in artificial intelligence systems. Lorentz could not understand why the unprecedented rapid development of computer technology did not lead to an increase in the quality of forecasts, i.e., as it was many years ago, today, the exact forecast was limited to 2-3 days. This issue is especially relevant in a big data environment. The reason for this phenomenon is dynamic chaos, which is extremely important when working with big data. The Lorenz system has a finite forecast horizon. The predicted processes have a property and the tendency diverges with the greater speed, the farther from the forecasting start point the forecast is made. This is determined by the so-called Lyapunov exponent. The forecasting time interval depends on this indicator, which is extremely important in the problems of high-quality data clustering by time intervals. In forecasting problems, the non-linearity factor is also especially significant. Nonlinear dynamics deprives many of the illusions in the process of robotization and the creation of systems with "artificial intelligence", which significantly limits the functionality of these systems. In such a case, it becomes necessary to move from system analysis to system synthesis and extract the most informative from the mass of variables. Thus, the forecast is moving from the realm of pure science to the realm of practical technologies. In [21], a new approach is proposed to methods for predicting the flow of requests and distributing the workload on available resources by assigning a "weight" to the so-called historical data. The use of historical data is not very new and is used quite often in economics. But in Big Data and cloud computing, where there is a constant replenishment of information, the need for research on the statistical homogeneity of data becomes extremely relevant.

Use of Big Data technology in the aviation industry. In the aviation industry, Big Data technology is used to: ensure flight safety; for timely maintenance, diagnostics and repair of aircraft units; to study passenger preferences; optimization of passenger traffic at the airport [10]. Big data aggregates technical, technological, mathematical and software tools that extract meaning from the data at the maximum intellectual level provided for in the project. At the same time, if we consider the aviation industry in the subject aspect, then we can fully attribute it to the leaders in the generation and accumulation of digital data, and a large niche opens up for such tools as artificial intelligence (AI), ML (machine learning), Big Data (BD), as well as for classic BI solutions and business intelligence tools [22,23].

According to the data of airlines that already have experience with BD, one of the most important subsystems in BD technology is the “System for diagnosing and predicting the technical condition of aircraft components and assemblies”. Based on the data obtained from the on-board diagnostic system,

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it becomes possible to implement the concept of "predictive maintenance" and predict failures of critical aircraft components. Another extremely important quality of BD is the possibility of implementing the technology of "digital twins" [24]. Digital twins are virtual models of physical objects and processes that imitate the operation of an aircraft engine in flight. This is possible when thousands of points and sensors for data collection are installed during the design and manufacture of the engine. In flight, a set of sensors create a digital information model of the physical and technical condition of the engine in real time, creating an information picture of the object's performance for a given period of time. Sensors are sources of physical data that are processed by the Big Data - Analytics software tool. All this helps to reduce costs and improve flight safety.

One of the widely and frequently used means of intellectual data processing is Data Mining [23,25]. Among specialists, it is believed that Data Mining is the fastest growing technology for discovering hidden useful knowledge in “raw” data. Unlike expert methods, Data Mining offers a method of "objective" selection of new knowledge. As tools for selecting new knowledge, this technology uses the technique of using templates of "patterns". Unlike statistical methods, where a relationship is sought between pre-prepared samples by calculating the correlation coefficient, in Data Mining these information sets, especially in the BD environment, are determined and formed programmatically, which can be attributed to the concepts of intelligence. There are five patterns and relationships used in Data Mining: association, sequence, classification, clustering, and chronology.

In artificial intelligence systems, neural technologies are currently being implemented quite widely and successfully in aviation. The main feature of the neuron is the ability to learn. The input of the neuron receives a set (vector) of data or objects. A sum of “weighted” data is formed in the neuron. The specified amount is compared with the threshold value, if the result of the comparison according to the given algorithm does not satisfy the conditions of the problem, then the input vector is modified. The main disadvantage of this technology is that again the "weight" of the input elements must be estimated by experts.

Use of Smart technologies in the aviation industry. For the aviation industry, as a result of an in-depth analysis carried out by specialists from the Institute for Statistical Research and Economics of Knowledge of the Higher School of Economics, a list of digital SMART technologies was developed and recommended in the following structural and functional format [4.26]: “Neurotechnologies and artificial intelligence”; "Distributed registry technologies"; "Quantum technologies"; "New production technologies"; "Smart Manufacturing Technologies (Smart Manufacturing; "Components of Robotics and Sensors"; "Wireless Communication Technologies"; "Technologies of Virtual and Augmented Reality"; "Laser and VLC Technologies"; "Technical SMART Diagnostics". In order to evaluate the effectiveness of each of the above technologies the success of industries and even states in implementing digital transformation was studied.The analysis revealed the following groups and SMART technologies:

1. The Neuro-technologies and Artificial Intelligence group combines such technologies as: computer vision, natural language processing, speech recognition and synthesis, decision support systems, neuro-interfaces, neuro-stimulation and neuro-sensing. Computer vision is one of the key artificial intelligence technologies that is actively used in transport. Determining the need for vehicle repairs seems to be very effective with the help of predictive maintenance systems. Vehicles with built-in neural interfaces will greatly simplify the management of cars, aircraft and water transport.
2. The “Distributed registry technologies” group contains: technologies for organizing and synchronizing data, technologies for ensuring the integrity and consistency of data, technologies for creating and executing decentralized applications and smart contracts.
3. The "Quantum technologies" group contains: quantum communications; quantum computing; quantum sensors. Currently, solutions based on quantum communications are at the development stage.
4. The New Manufacturing Technologies Group integrates: digital design, mathematical modeling and product or product life cycle management (Smart Design).
5. Group "Components of robotics and sensors". Digital transformation has embraced many industries, and one of the first to respond was transport and logistics, covering aviation, road, rail, and sea transportation. One of the fastest growing segments of robotics is unmanned aircraft. In aviation robotic transport for unmanned control, as a rule, a radio channel is used. The disadvantage of the radio channel is that it is quite often subjected to external opposition. Under these conditions, the principles of safe control of unmanned traffic flows VLC technology acquire unprecedented significance and relevance [26]. Unmanned vehicles are a

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strategic trend in the development of many industries, which is based on a complex of advanced artificial intelligence systems.

6. Group "Wireless Communication Technologies". This group contains: WAN (Wide Area Network); LPWAN (Low Power Wide Area Network); WLAN (Wireless Local Area Network); PAN (Personal Area Network) RFID (HF and UHF tags); Satellite communication technologies; VLC technologies. They will enable the operation of smart road infrastructure, intelligent transport systems and, ultimately, unmanned ground transport.

7. The Virtual and Augmented Reality Technologies group contains VR/AR content development tools. At the moment, the level of use of VR/AR content development tools in the transport industry is low.

An analysis of literary sources in the subject area showed that the quantitative criterion for the degree of use of digital transformation technology in the aviation industry is digital maturity. The main drawback of all the proposed methods in assessing the level of maturity is a differentiated approach to a digital object or digital technology. However, by definition - "Digital transformation" differs from "digitalization" in its integral approach to assessing digital maturity, which is implemented in the form of mathematical convolution.

Use of Smart technologies in aviation enterprises. In contrast to the level of digital maturity of the industry, six areas have been developed and are proposed for enterprises in assessing digital maturity (Fig. 1) [28].

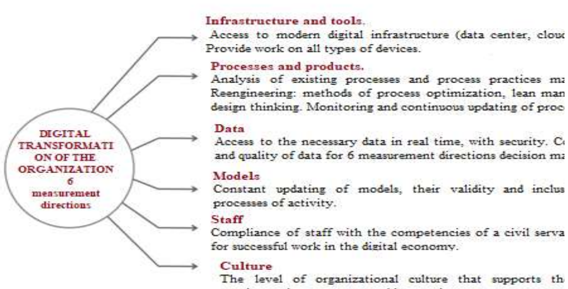

Figure 1. Directions in the assessment of digital maturity [28]

1. Infrastructure and tools. An industry enterprise has the opportunity and access to modern system digital support: technical, software, mathematical, informational, organizational and methodological.

2. Processes and products. In this direction, existing business processes and the compliance of processes with existing standards are analyzed.

3. Data. The data correspond to the context and strategy of the enterprise development, are examined for qualitative and statistical homogeneity and are supported by the monitoring of relevance and value.

4. Models. Models form the intellectual base of the digital system, implement the functions of assessing and predicting the quality of business processes. Assess the risks of control and decision making.

5. Staff. Staff are evaluated individually according to a set of quality indicators. The digital system has a formal model and technology for differentiated and integral assessment of the quality of staffing. A system for monitoring the process of staff retraining has been created.

6. Culture. The level of organizational culture, the readiness of employees to introduce innovations, generate new ideas, work with a large amount of information, and new technologies are assessed.

These criteria, at the contextual level of the system, are differentiated assessments of the digital maturity of the current state of the enterprise. With any chosen approach to assessing digital maturity, it is necessary to control the target state of the organization, set by the requirements of digital transformation.

Formal provision of risk management processes in the digital transformation of enterprises. Each direction (Fig. 1) contains a procedure and a documented act of control and decision making. Control is necessary for diagnosing the current state of the object according to a number of technical and economic indicators and making forecasts for the future. Modern organizational and technical business systems operate in conditions of statistical uncertainty and fuzzy data. Decision-making under these conditions is accompanied by risks. The works of a number of authors have proved that these risks in terms of socio-economic content and consequences are the risk of the producer and the risk of the consumer. Risks are of stochastic origin and have a multifactorial functional content and form. Risks can be quantified only by formal mathematical and simulation tools [27,29,28].

In [26], the issues of the software for the diagnostic process were studied in order to assess the influence of various factors on the diagnostic result, especially on control errors, which are considered control risks. The influence of statistical laws of distribution of diagnostic parameters on probable errors of diagnosis was studied. At the same time, various initial hypotheses and statistical conditions were investigated in all studies. For quantitative evaluation, probabilistic models for estimating control errors with a one-limit constraint, a controlled parameter from below, are given, which have the following form:

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$$P_{ff} = \sum_{t=1}^{n} \frac{1}{\sqrt{2\pi}} \int_{t_i}^{t_{i+1}} e^{-\frac{t^2}{2}} dt \cdot \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z_i} e^{-\frac{z^2}{2}} dz \quad (1)$$

$$P_{fu} = \sum_{t=1}^{n} \frac{1}{\sqrt{2\pi}} \int_{t_i}^{t_{i+1}} e^{-\frac{t^2}{2}} dt \cdot \frac{1}{\sqrt{2\pi}} \int_{z_i}^{+\infty} e^{-\frac{z^2}{2}} dz \quad (2)$$

where, the probability of an undetected failure (defect) is – P_{uf}, and the probability of a false failure (defect) is – P_{ff} .

An undetected failure (defect) is considered to be the case when the controlled parameter is outside the permissible limits, and the control system registers the fact that the parameter is within the permissible limits. And vice versa, when the controlled parameter is within acceptable limits, and the control system registers the fact that the parameter is outside the acceptable limits. The above models use the hypothesis that the statistical laws of distribution of all parameters belong to the Gauss law.

In [27], the hypothesis of the distribution of the diagnostic parameter according to the Weibull law, and other parameters according to the Gauss law, is studied. Using the integral function of the Weibull law, an expression was obtained in the final form for calculating the probability P_{ff} and P_{uf}

$$P_{ff} = \sum_{i=1}^{k} \left(e^{-\frac{S_i^{\beta}}{\alpha}} - e^{-\frac{S_{i+1}^{\beta}}{\alpha}} \right) \times \left[\frac{1}{\sigma_y \sqrt{2\pi}} \int_{S_н}^{S_i - 3\sigma_y} e^{-\frac{y^2}{2}} dy + \frac{1}{\sigma_y \sqrt{2\pi}} \int_{S_в}^{S_i + 3\sigma_y} e^{-\frac{y^2}{2}} dy \right] \quad (3)$$

$$P_{fu} = \sum_{i=1}^{k} \left(e^{-\frac{S_i^{\beta}}{\alpha}} - e^{-\frac{S_{i+1}^{\beta}}{\alpha}} \right) \cdot \frac{1}{\sigma_y \sqrt{2\pi}} \int_{S_н}^{S_i - 3\sigma_y} e^{-\frac{y^2}{2\sigma_y^2}} dy + \sum_{i=1}^{k} \left(e^{-\frac{S_i^{\beta}}{\alpha}} - e^{-\frac{S_{i+1}^{\beta}}{\alpha}} \right) \cdot \frac{1}{\sigma_y \sqrt{2\pi}} \int_{S_в}^{S_i + 3\sigma_y} e^{-\frac{y^2}{2\sigma_y^2}} dy \quad (4)$$

The research [28] explores the hypothesis of non-deterministic norms. The standards are designated as: S_l – lower standard and S_u – upper standard and their statistical characteristics in the form of distribution laws

$$\Theta_1(S_l) = \frac{1}{\sqrt{2\pi} \cdot \sigma_l} e^{-\frac{(S_l - S_{lm-s})^2}{2\sigma_{lu}^2}};$$

$$\Theta_2(S_t) = \frac{1}{\sqrt{2\pi} \cdot \sigma_t} e^{-\frac{(S_t - S_{tm-s})^2}{2\sigma_t^2}} \quad (5)$$

To study this version of the hypotheses, a simulation approach was used and an algorithm was develope*d. Based on the results of simulation modeling, a 3D model was built, shown in Figure 2.*

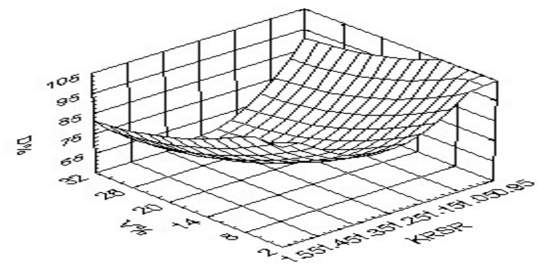

Figure 2. 3D D% reliability model as a function of the ratio of the V% uncertainty measurement to the uncertainty of the controlled parameter and the values of the KRSR standard

In the 3D format in Figure 2, the spatial system connection of the statistical control parameters is visually displayed. Hidden combinations that really exist and affect the reliability of control in all their multitude should be understood as augmented reality

3. METHODS AND RESULTS OF THE STUDY

Methods and results of the study. The purpose of the study is to develop a formal methodology for quantifying the level of digital maturity of the aviation industry and enterprises.

The methodology of this work involves the stages of theoretical and experimental research, which include: analysis of methods for diagnosing aircraft units and systems, research of sensors for converting the physical parameters of engine working processes into an electrical signal, research of methods for secure transmission of information to control unmanned vehicles, development of a mathematical model for quantitative assessment of the risks of monitoring diagnostic parameters.

The research methodology is based on a systematic approach. In this interpretation, the system is considered as an integrated set of control digital control agents, where agents can be digital technologies that are in system communication with each other. As applied tools for formalizing the methods of a systematic approach, in the tasks of assessing and predicting technological and operational dynamics, the following are used: technological analogies, functional dependencies, probabilistic and simulation models, agent-based approaches. To conduct a computer experiment, a developed software application is used.

On the basis of the developed models, data from experimental and statistical studies and a software application, it is planned to implement a computer experiment in order to assess the adequacy of the theoretical premises and results of computer simulation on the actual experimental material.

Methods and tools for diagnosing aircraft engines. In aviation, methods for managing the operational reliability of an aircraft and diagnostics of aircraft units and systems occupy an extremely important place, since these technologies determine flight safety. Diagnosis methodically can be divided into two options. The first option is based on the technology of direct measurements of physical parameters (indicators) that determine the technical condition of the object. This option, as a rule, provides for partial disassembly of the diagnosed object, which is a significant drawback. The diagnostic parameters of an aircraft engine have the following physical nature: Thermo-Gas Dynamic; thermal; vibroacoustic; optical-visual; hydrodynamic; piezoelectric; physical and chemical; and some others.

The second method without demountable diagnostics uses indirect parameters that are statistically or functionally related to the controlled workflow. This method is more typical for diagnosing an aircraft engine. Diagnosis of the technical condition of the engine is carried out by measuring the values of diagnostic parameters, comparing the measured value with the standard level, and making a decision on further technological actions. For these purposes, various measuring instruments and specialized diagnostic complexes and systems are used.

One of the main problems in engine diagnostic technologies is sensors that convert the physical parameters of the engine's working processes into an electrical signal. One of the common sensors is inductive. Capacitive sensors are also widely used. To study dynamic processes, high metrological indicators are demonstrated by piezoelectric sensors that generate an electric charge when the pressure changes on its contact planes. At the same time, the use of this sensor is accompanied by a number of features and requirements for circuitry and the need to match the input impedance of the measuring channel, since the output impedance of such a sensor is very high. Therefore, a very high input resistance of the measuring circuit and the use of special cable connections with high impedance are required [29].

To register thermal parameters, thermocouples or thermal resistances are used, and for remote control, pyrometers, structurally designed in the form of devices - thermal imagers. The objects of non-contact thermometric diagnostics can be both the engine as a whole and its individual units and parts. Reproduction of an infrared image by line analysis allows you to get a thermal map of the observed area. Among the devices built on this principle, the TVS-200 thermal imager should be noted.

At present, the technology of in-place diagnostics called "information phase-time technology" is being intensively developed. This type includes the so-called vibro-acoustic method [30]. Particularly promising is the method of non-contact diagnostics of an aircraft engine using laser vibrometers. Testing of laser vibration diagnostics was carried out on the following aircraft engine units: front gearbox; rear drive box; hydraulic pump; oil pump; generator. As an example, Figure 1 shows the vibrogram of the front gearbox of the D-30KU-154M engine. Figure 3 shows the direct vibration spectrum of rotation of rotors and drive units. The spectrum shows that the vibration level at the shaft speed is commensurate with the vibration level of the rotor.

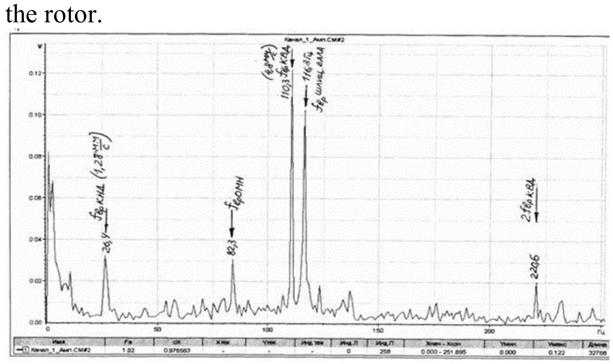

Figure 3. Aircraft engine vibration signal [29]

The physical interpretation of these pulses indicates the presence of mechanical shocks, which have been termed "shock pulses". Recently, new information processing technologies with the involvement of computer technology have appeared. So, for example, a technique for assessing the technical condition by the integral envelope of the signal spectrum is being investigated. Industrial variants of vibration measuring equipment have a wide variety in terms of dimensions, price, power sources, accuracy, a set of diagnostic functions, etc. Portable and stationary diagnostic systems will have constant access to the central database of "big data".

Methods and means of remote control and information protection based on VLC technologies. A big drawback that accompanies the work on the study of aircraft engines carried out in the laboratory is the low environmental friendliness of the laboratory space. Therefore, the measuring equipment is placed in separate rooms, and the diagnostic information sensors installed on the engine are connected to the diagnostic equipment by cable connections, which is extremely untechnological. Recently, a new technology for wireless transmission of information has appeared that uses not radio waves, but the visible light of LED illuminators. The communication network using LEDs is highly reliable and provides high electromagnetic immunity from other sources of natural and artificial electromagnetic radiation. This technology is called VLC (Visible Light Communication) and provides wireless data transmission to photodetectors along with the light emitted by LEDs [26]. In addition, Visible Light Communication (VLC) technology has a high bandwidth of 500 Mbps.

One of the promising and still poorly developed areas of using VLC technologies is the military application in unmanned aerial vehicles (drones). Currently, drones are controlled via radio channels and are extremely vulnerable to electronic warfare. The use of the so-called "flock" of drones is also destroyed by radio means. But if the "flock" contains one or two more powerful drones with a program for controlling light coded signals, having a control radius of hundreds of meters for all low-power drones, then radio countermeasures become ineffective. Figure 4 shows the structural and functional model of the system for transmitting information over the VLC control channel of an aircraft.

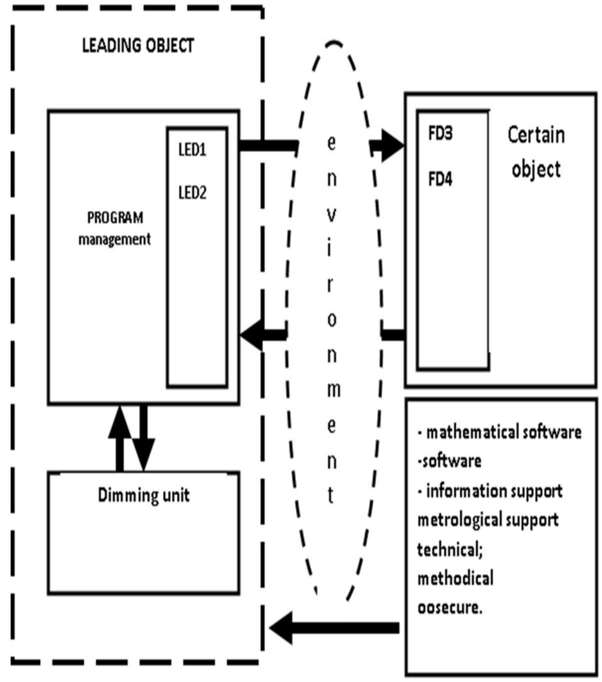

Figure 4. Structural and functional model of the information transmission system via the VLC channel in the aircraft control system

In this figure: the leading object is the head control unit (control drone); solution program - the main control program for receiving and transmitting information over the VLC channel; LED1, LED3 - white light LEDs; LED2, LED4 - infrared LEDs; FD1, FD3 - photodiodes of the visible optical range; FD2, FD4 - photodiodes of the infrared optical range; dimming unit - VLC system driver; slave object - a set of drones; WEDNESDAY - air section on the line of optical communication VLC communication.

In order to improve information reliability, the proposed technical solution provides for duplication of information exchange, which is shown in Figure 4, with two channels: a visible (white) light channel and an infrared channel. In Figure 4, the reception and transmission of white light is implemented on LED2, LED4, PD2, PD4, and the reception and transmission of infrared information is carried out by diodes LED1, LED3, PD1, PD3.

In any functional target application of the VLC complex, there is a system of control and decision making. The control process, as shown above, is accompanied by risks. The quantitative level of risks depends on the system composition of many statistical and deterministic factors and parameters. It is possible to quantify and predict risks only by formal methods, for which the literature offers, as noted above, mathematical models for various initial conditions in the control system. The final phase of the control process is decision making, which completes the diagnosis function.

Mathematical support of the system of diagnostics of flying objects. Practice shows that the most critical link in management is the implementation of the results of control and decisions in the form of restoring the regulatory functions of the control object. This function is random in nature [29]. In this regard, there is a general problem of assessing and predicting risks in a closed control cycle (for example, in the control system for the technical condition of aircraft of all types).

In real systems, feedback is represented by a link with the function of corrective (regulatory) impact on the control object. In automatic control and regulation systems, the feedback is negative, which is a condition for stability, and if the negative feedback turns into a positive one, the system loses stability.

In this model, the decision to restore the normative working functions and the implementation of corrective actions on the object (process) for this purpose is carried out by the subject, which brings its own specifics to the solution of the problem of stability. Decision making is approached from different perspectives in different sources. So in the works of S. Optner, S. Yang, S. Nikonorov, it is believed that “decision making” is already a solution to the problem in the complex of “analysis and synthesis”. Without synthesis, there is no point in doing analysis. In the works of these authors, the control process was considered from deterministic positions, which, as modern practice shows, is a significant simplification of the real situation and a decrease in the robustness of the system. In this regard, the problem arises of studying control processes taking into account feedback in the conditions of the statistical nature of control agents. In practice, this task becomes especially relevant in control systems for dynamic objects, for example, control of unmanned aerial vehicles. In the maintenance of a complex object, for example, aircraft, the restoration of operability is solved by carrying out certain corrective procedures. Under these conditions, the psychological type of a person (the human factor) begins to play a role, making decisions and correcting the system. Accounting for this factor is also necessary in modeling (in this article, this problem is not included in the objectives of the study).

For a quantitative study of the control process with feedback, a simulation model is proposed that contains a control unit and a system “recovery” unit, provided that the controlled parameter has lower and upper tolerance standards $\Delta = Sl - Su$. In this case, it is considered that the norms of the value are deterministic. The algorithm of the simulation model is illustrated in Figure 5. The functional purpose of model blocks 1, 2, 3, 4, 5, 6 has a typical known purpose shown in the blocks. Block 1 differs in that the statistical characteristics of the decision implementation subsystem (correction) are introduced. In block 7, the error value of the "regulation" of the system is generated. In block 8, the total value of the "regulating" impact on the system is calculated, consisting of a random Δsl and a determined planned component Δpl. Functions of the following blocks after 9 pairs. The only difference between them is that at the end of the branch, the counter of the corresponding deviation type will be incremented. Unlike the previously considered cases, where a deviation (defect) was detected, but no measures were taken to eliminate the problem, in this case these measures are taken and in blocks 11 and 15 the value of the corrective action on the controlled process is generated. In blocks 13 and 17 counters work: "false failure" - Nff, "undetected failure" - Nuf. The functions of blocks 18 and 19 are similar to the last two blocks of the previous models.

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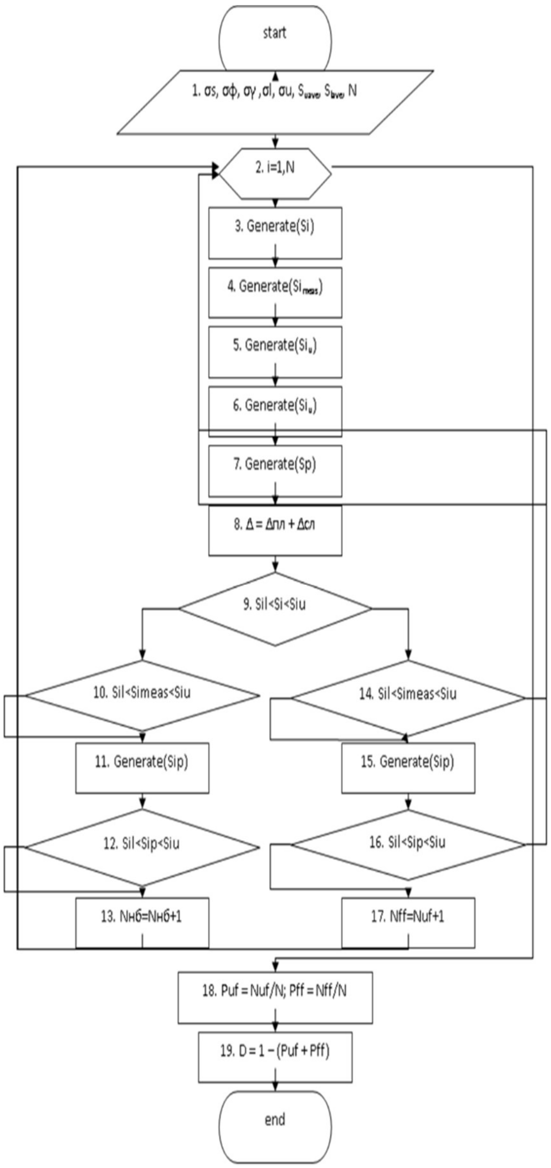

Figure 5. Simulation model for correcting the control result

4. THE RESULTS OF COMPUTER SIMULATION.

The results of the computer simulation, in order to assess the impact of the statistical uncertainty of the feedback parameters on the probable risks of the control and decision-making system, are presented in graphical form in Figures 6-7. In the figures, as an example, only the probable risks Pff of undetected defect (failure) are given.

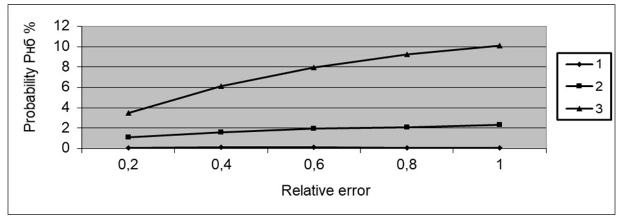

Figure 6. Probability of an undetected defect (undetected failure) Pff without feedback

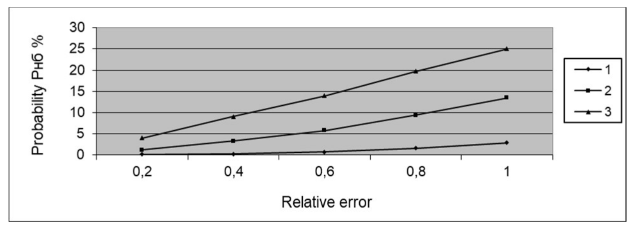

Figure 7. Probability of the risk of an undetected defect (undetected failure) Pff, taking into account the statistical properties of the feedback

As follows from the simulation results, regardless of the tolerance value, the simulated level of risk of an undetected defect Pff in a feedback system is much higher (Fig. 7) than in the absence of feedback (Fig. 6).

5. CONCLUSION

The aim of the article is to develop a methodology for quantitative assessment of the risks of control and decision-making in the control system of complex objects using the example of aircraft. Manned and unmanned vehicles are considered as aircraft. As a result of the analytical review, it was found that the risk is presented in work as a multifactorial stochastic-programmable system in the context of the digital transformation of the industry and enterprise. It was revealed that the process of digital transformation of an aviation enterprise is currently determined by the level of digital maturity and is correlated with the dynamics of such digital industry technologies as: "Maintenance of aviation equipment" and "Components of robotics and sensors", and in the structural and functional technologies of digital transformation of an enterprise the most promising and significant are: "Personnel"; "Models"; "Infrastructure and tools"; "Processes and Products"; "Data". The risk value evaluates the synergy of digital transformation agents and augmented reality factors, which is not explicitly included in analytical models. Mathematical and simulation models have been developed for quantitative risk assessment. The results of the computer experiment showed that the statistical probability of control errors (risks) to a much greater extent depends not on the measurement error, but on the quantitative composition in the form of the ratio of the standard deviation (uncertainty) of the measurement instrument error to the standard deviation of the controlled parameter. Presentation of modeling results in a 3D spatial form allows you to visually evaluate the overall systemic picture of the control results, with all possible compositions of the statistical characteristics of control agents.The results obtained can be used as mathematical and methodological support for automated decision-making quality control systems in emergency management services.

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REFRENCES

[1] Rogers D.L. (2017) Digital transformation: a practical guide / translated from English. M.: Tochka,. p. 7.
[2] Gribanov Yu.I. (2019) Digital transformation of socio-economic systems based on the development of the institution of service integration: dis. . Dr. Econ. Sciences. St. Petersburg: St. Petersburg State University of Economics, URL: https://unecon.ru/sites/default/files/dissgribanovui.pdf (accessed 08.10.2020).
[3] Isaev E.A., Korovkina N.L., Tabakova M.S. (2018) Assessing the readiness of a company's IT department for digital business transformation // Business Informatics. No. 2 (44). pp. 55-64. DOI: 10.17323/1998-0663.2018.2.55.64.
[4] Methodological recommendations for the digital transformation of state corporations and companies with state participation / Ministry of Digital Development, Communications and Mass Media of the Russian Federation. URL: https://digital.gov.ru/uploaded/files/mr-po-tst-gk.pdf (date of access: 08.10.2020).
[5] Prokhorov A., Konik L. (2019) Digital transformation: analysis, trends, world experience. M.: AlyansPrint. 368 p.
[6] Abdrakhmanova G.I., Bykhovskiy K.B., Veselitskaya N.N., Vishnevsky K.O., Gokhberg L.M. (2021) Digital transformation of industries: starting conditions and priorities. XXII International Scientific Conference on the Development of the Economy and Society, Moscow, p. 11-16.
[7] Digital maturity assessment //cdto.wiki› ..
[8] Strategy for achieving digital maturity in vocational institutions ruresh.ru›Info-center›
[9] Methodology for calculating the indicator "achieving "digital maturity"...//consultant.ru›document/cons_doc_la...
[10] Methodological provisions for the integration of high-tech industrial enterprises into the digital space (on the example of aircraft manufacturing enterprises) ” //cyberleninka.ru›article/n/metodich...
[11] State Program "Digital Kazakhstan" (2017), Approved by the Decree of the Government of the Republic of Kazakhstan dated December 12, No. 827
[12] Altukhov A.I., Dudin M.N., Anishchenko A.N. (2020) Digital transformation as a technological breakthrough and transition to a new level of development of Russia // Food policy and security. - Volume 7. - No. 2. - P. 81-96. – doi: 10.18334/ppib.7.2.100923.
[13] Digital transformation and digital business maturity//datalab-nsu.ru›digital-transformat...
[14] Big Data - what are big data systems? Development...//promdevelop.ru›industry/big-data.
[15] Big Data in Aviation: 4 Case Studiesbigdataschool.ru›blog/big-data...
[16] Buyul A., Zefel P. (2001) SPSS: the art of information processing. Analysis of statistical data and restoration of hidden patterns. ISBN: 5-93772-032-6 Moscow: DiaSoft, 608p.
[17] Cloud computing - what is it, what usage models exist//stekspb.ru›blog/oblachnye-vychisle...
[18] Maria Ashraf, Muhammad Shiraz, Almas Abbasi, Saleh Albahli. (2022) "Distributed application execution in fog computing: A taxonomy, challenges and future directions". Journal of King Saud University – Computer and Information Sciences 34 3887–3909. https://doi.org/10.1016/j.jksuci.2022.05.002
[19] Dalia Abdulkareem Shafiq N, Z Jhanjhi, Azween Abdullah. (2022) "Load balancing techniques in cloud computing environment: A review" Journal of King Saud University -

Computer and Information Sciences Volume 34, Issue 7, July, Pages 3910-3933, https://doi.org/10.1016/j.jksuci. 2021.02.007

[20] Kalka Dubey, S.C.Sharma. (2022) "An extended intelligent water drop approach for efficient VM allocation in secure cloud computing framework", Journal of King Saud University - Computer and Information Sciences Volume 34. Issue 7, July, Pages 3948-3958, https://doi.org/ 10.1016/j.jksuci.2020.11.001

[21] Wiem Matoussi, Tarek Hamrouni. (2022) "A new temporal locality-based workload prediction approach for SaaS services in a cloud environment", Journal of King Saud University - Computer and Information Sciences Volume 34, Issue 7, July, Pages 3973-3987, https://doi.org /10.1016/j.jksuci.2021.04.008

[22] Rakhmetullina S.Zh., Bugubaeva A.Zh. (2018) Application of Data Mining technology to predict air pollution. // Bulletin of the East Kazakhstan Technical University. D. Serikbaeva. No. 4 (82). - p. 177-183.

[23] Tasks of Data Mining. Classification and clustering [Electronic resource]: informational article. – Access mode: http://www.intuit.ru/department/database/data mining/5/ (Date of access: 11/04/2020).

[24] What is a digital twin (Digital twin): technology and its ...future2day.ru›texnologiya-cifrovyx...

[25] Methodological recommendations for the digital transformation of state corporations and companies with state participation / Ministry of Digital Development, Communications and Mass Media Russian Federation. URL: https://digital.gov.ru/uploaded/files/mr-po-tst-gk.pdf (date of access: 08.10.2020).

[26] Alibekkyzy K, Wojcik W, Vyacheslav K, Belginova S. (2021) Robust data transfer paradigm based on VLC technologies. Journal of Theoretical and Applied Information Technology. 2021 Little Lion Scientific. 15th February. Vol.99. no 3.

[27] V. A. Kornev A. A. Makenov, A. H. Mashekenova, R. C. Radjabov. (2020) Quality assessment of multi-parameter control of vehicle complex systems efficiency //Series of geology and technical sciences.-volume 2, number 440, 96 – 102 https:/ /doi.org/10.32014/2020.2518-170X.36

[28] Yesmagambetova Marzhan, Keribayeva Talshyn, Koshekov Kairat, Belginova Saule, Alibekkyzy Karlygash, Ospanov Yerbol. "Smart technologies of the risk-management and decision-making systems in a fuzzy data environment" Indonesian Journal of Electrical Engineering and Computer Science. Vol. 28, no. 3, December 2022// ISSN: 2502-4752, DOI: 10.11591/ijeecs.v28.i3.pp1-1x

[29] Richard C. Dorf (Ed.) (2016)The Electrical Engineering Handbook: Sensors, Nanoscience, Biomedical Engineering and Instruments. 1st edition. CRC Press, - 392 p.

[30] Vibro-acoustic non-destructive testing //tehnoinfa.ru›vibrodiagnostika/1.ht...