DIGITAL TWIN OF THE QUALITY MANAGEMENT SYSTEM FOR ENVIRONMENTAL CONTROL OF THE NEAR-AIRDOM ENVIRONMENT

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ABSTRACT

The purpose of this study is to develop a formal approach in order to assess the reliability and risks in the airfield control system. This referred to the digital transformation of the aviation industry business. To achieve this goal, the following tasks are solved: primarily, the geometric model of controlled airspace were justified in the area of the Almaty airport. This geometric model is presented in the form of an atmospheric cylinder with a given radius and height. In addition, there was developed a functional and technological model of the airfield quality monitoring system in Almaty. This was based on the use of unmanned aerial vehicles with constant radio communication operated by environmental control center at the airport. Also, there was built a virtual-spatial information 3D model of atmospheric pollution near the aerodrome environment in the "Digital Twin" format. Therefore, a fuzzy model of an integral criterion for assessing air quality in the controlled area of the Almaty airport has been developed. Additionally, there have been developed a probabilistic model on order to assess the reliability and risks of air pollution control in the near airfield environment.

Keywords: *aviation industry, digital twin, risk, technology, model, reliability, probability*

1. INTRODUCTION

In the geosystem approach to monitoring technogenic atmospheric pollution, there is an active use of innovative digital technologies based on fundamental and applied research. In urbanized areas, atmospheric pollution by level and component physico-chemical composition has a pronounced local character. In the context of the digital transformation of environmental control quality management processes, there are ideas of virtualization of the surrounding world in order to build its global models, which adequately fits into modern trends in scientific thought. In the studies of the last decade, it is considered productive to consider the digital transformation of environmental innovations in this vein. This approach finds support in the state documents for the development of the Republic of Kazakhstan, in which one of the priorities is the scientific direction in the field of environmental monitoring until 2030. [1-4]. Digital transformation in the field of ecology involves relying on artificial intelligence technologies, the use of unmanned vehicles, real-time Earth remote sensing systems, the formation and operation of Big Data ecological systems, Digital Twins technologies [5-9]. In the applied version, the Digital Twin of an object is its mathematical model associated with a real information process.

In this study, one of the objectives of developing a methodology for improving the reliability of monitoring the level of air pollution in the near-aerodrome environment in the context of digital transformation of business processes in the aviation industry is achieved. As a mechanism for achieving the goal, the Digital Twin technology was analytically justified and chosen. To effectively solve this multifaceted problem in the conditions of an aviation enterprise, a number of approaches have been theoretically studied and practical recommendations have been proposed.

The digital transformation that replaces digitalization is called the digital revolution in all spheres of human activity, which will lead to the creation of a huge amount of geospatial data, which are the basis for innovative digital technologies. As a result of the analysis, a list of such integrated digital technologies was created, representing digital transformation, which included: “Neuroethologies 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"; "Digital Twin"; "Technical SMART Diagnostics" [10-12]. At present, it is already widely practiced similar digital geosystem approaches and technologies are used, such as GIS, BIM, etc. BIM is a 3D model of an object associated with Big Data, where each element of the 3D model has an individual specification. There is still an information gap between technologies at this stage, which deprives digital transformation systems of the main quality - integration. For example, geographic information systems (GIS) and real objects of other functional purposes are still poorly coordinated, and they are not integrated with the BIM system. The integrating factor in digital transformation is a seamless 3D blueprint for managing facilities using internal and external data with the same interface, which is an important feature of the business model. A serious disadvantage is the gap between the geospace and the real object, when the same objects of the real world can be redundantly stored in different projects, which leads to unreasonable resource costs and data heterogeneity. There are no standards for expressing that two geosystem representations describe the same real world object.

This problem can be smoothed out by intellectualizing the system based on formal approaches using stochastic, simulation, agent-based and fuzzy modeling in the Digital Twin system. A digital twin is a digital three-dimensional information image of a real environment. The Digital Twin technology is just beginning to acquire its functional and informational image. The digital twin in the presented work is a virtual representation of a complex airfield ecosystem in the form of a geometrically configured “point cloud”. The technology of digital twins should be considered at the present stage the most effective mechanism in ensuring the reliability of monitoring in such a field as the environment. In the noted works, the following indicators are given that demonstrate the effectiveness of the implementation of digital twin technology: reduction in production costs; reduction of systemic and operational risks; introduction and development of new innovative service models; reducing the need for material and organizational resources; increase in the turnover of goods and services.

Currently, the smart technology, collectively known as the "Digital Twin", according to Accenture and Dassault Systèmes, will generate $1.3 trillion in economic benefits and 7.5 Gt CO_2 reductions over the next 10 years.

2. LITERATURE REVIEW

2.1 General principles and criteria for digital transformation of the air quality management system in the aerodrome environment.

A literary review of works on the problem under study shows that the new digital paradigm is to "look beyond the boundaries of the usual understanding of life." Ultimately, a new digital technological approach is born and proposed called “digital transformation” [13,14,15]. Digital transformation, both at the functional and technological levels, has not yet acquired clear contours and differences from the traditional definition - digitalization. Attention is drawn to this fact and studied in detail in [16, 17]. The work [18] provides an extensive and in-depth analysis of the current state of digital transformation, which was made on the basis of a study of 206 peer-reviewed articles. In the author's analysis of the state of this subject matter, the scientific and practical areas of digital transformation were considered and directions for future research are suggested. The analysis shows that the new digital reality has its own specifics in each business project and "managers must adapt their business strategy to new" digital technologies.

The paper [19] proposes the results of a study in order to give a clear definition of the “term “digitalization” and to distinguish between similar terms”. The paper notes that the main goal of the transition to new digital technologies, especially the approach that integrates all known technologies, called "digital transformation", is the hope of increasing its competitive advantage, relying on service virtualization. In real practice, there is a need for a clear understanding of how digital twins work. The answer should be sought in the fact that the digital twin is a virtual entity of a dynamic product, including an ecosystem that can be used in real time for modeling, visualization, forecasting, demonstrating certain properties and functionality of an object or product.

For the user, the digital twin is represented by a model with a list of variables that can be varied, and

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thus predict the behavior of the object. Using iterations, you can get a result with a fairly high accuracy and great savings in time and resources. These results are already being confirmed in practice, since modeling the behavior of an object as a whole, in various conditions and contexts, could be assessed visually or by objective control. The digital twin allows you to evaluate the result in real time, which led to an immediate reaction through the feedback link in order to restore the normative functionality of the control object or its performance. This technology gives a positive result at all stages of the life cycle of the object under study: design, manufacture, testing, maintenance and even disposal, and at the operating stage it is more accurate to predict their behavior and take the necessary measures in advance [20].

In the digital transformation of the sphere of ecology and nature management, the solution of the interaction of fundamental and applied research based on digital twin technologies, one of the key tasks of air quality management through environmental monitoring was solved [21,22]. From these positions, the possibility of radical improvement of the system of environmental monitoring of the near-aerodrome environment is considered in the program documents of many countries. Specialists are of great interest in the development of "digital twins" in environmental applications, where two approaches are proposed: technological and conceptual. In ecology, the digital twin of air quality monitoring is presented as a mathematical model associated with a real atmospheric object. At the application level, a “digital twin” “designates a process or an object whose state dynamics is fully modeled mathematically, and all its important indicators are digitized, corresponding models are built that calculate all possible states of the object” [23, 24].

One of the main problems in digital twin technologies is the collection of primary information about the technical and economic state of a real object, and in the monitoring mode, periodically update this digital field or a cloud of digital points [25]. Various sensors are used for this purpose [26]. Each point is an information carrier of measurement results, expertly substantiated parameters of pollution of the near-aerodrome environment. The works [27-30] and ICAO standards propose the following indicators to be monitored taking into account their impact on the human body: CO, CO_2, NO, NO_2, SO_2, H_2S, O_3 NH_3 and particulate matter.

In accordance with modern digital concepts, the simulated environment is a "virtual reality" and part of the "metauniverse" [19]. "Metaverse", as noted in the publications, "is not a new term." The first concepts of the metaverse had only fantastic outlines associated with travel outside the galaxy. It is a cross between the real and fictional world. At present, the concept of “metaverse” has begun to acquire practical contours and penetrate into many areas of life, such as: social networks, the real estate sector, investments, work, augmented reality, the cryptocurrency world, online games, etc.

At the same time, digital twins in practical implementation have disadvantages, consisting in their complexity and requiring high costs for implementation and maintenance.

2.2 Scientific problem.

In the proposed study, attention is focused on assessing the quality of management in complex organizational and technical systems using the example of the environmental pollution control functionality. The main scientific and practical idea of the study is to study the quality factors of managing complex multi-parameter systems under conditions of statistical uncertainty and fuzzy data, which lead to risks at the decision-making stage. The total management risk contains subjective and instrumental components. In connection with the introduction of artificial intelligence technologies in the environment of digital transformation, the subjective component of risk decreases, but at the same time, the instrumental component of control risk increases. The instrumental component of risk is determined by the uncertainty of control. The overall reliability and risks of control are determined by the system composition of statistical laws and characteristics of all control agents, which can be quantified only by involving formal probabilistic, simulation and fuzzy sets. An important circumstance, which, as a rule, was not taken into account in known works, is the need to take into account the statistical properties of the standards. Taking into account the above arguments, there is a need in the proposed study to solve two main scientific and practical problems: the development of a formal method for quantitative assessment of the quality of management of a complex multi-criteria organizational and technical system under the conditions of statistical uncertainty of management agents under deterministic standards; formalization of the process of quantitative assessment of decision-making risks under conditions of statistical uncertainty of standards.

3. METHODS

The work consists of theoretical studies based on a formal platform and experimental studies of real mass dynamic processes. Probability theory and mathematical statistics, simulation modeling, fuzzy set theory, methods of expert assessments, agent-based approach were used as sections and apparatuses for formalizing the processes under study. For the processing of experimental data, the apparatus of mathematical statistics and the professional software package Statistica were used. At the final phase of the research, an assessment was made of the adequacy of theoretical premises to practical data from the field of operation of real objects. The contextual functional in the study considered the process of control.

4. RESEARCH RESULTS

4.1 Virtual paradigm for monitoring spatial pollution of the near-aerodrome environment.

The purpose of theoretical research is to develop a formal approach to assessing the reliability and risks in the airfield pollution control system in the context of digital transformation of the aviation industry business. The assessment of the adequacy of the theoretical assumptions to the real data was carried out by means of a computer experiment.

To achieve the goal, the following tasks are solved in the scope of the proposed article: substantiation of the geometric model of controlled airspace in the area of the airport in Almaty; development of a functional-technological model of the airfield atmosphere quality monitoring system in Almaty; building a virtual-spatial 3D model of atmospheric pollution near the aerodrome environment; development of an information model of the results of monitoring the spatial pollution of the near-aerodrome environment in the "Digital Twin" format; development of formal models for air pollution control near the aerodrome environment and forecasting control risks. To achieve the goal, the following tasks are solved in the scope of the proposed article: substantiation of the geometric model of controlled airspace in the area of the airport in Almaty; development of a functional-technological model of the airfield atmosphere quality monitoring system in Almaty; building a virtual-spatial 3D model of atmospheric pollution near the aerodrome environment; development of an information model of the results of monitoring the spatial pollution of the near-aerodrome environment in the "Digital Twin" format; development of formal models for air pollution control near the aerodrome environment and forecasting control risks.

In all spheres and sectors of the Republic of Kazakhstan, government documents regulate the projects of "digitalization" of business processes to switch to new approaches based on the "Digital Transformation" platform [2]. The digital transformation platform integrates such new technologies as: "Robotics and sensors"; "Digital twin"; Big Data and Fog Computing; "Technologies of virtual and augmented reality"; "Neurotechnologies and artificial intelligence"; "New production technologies"; and a number of other technologies [11]. In the subject area under study, the greatest scientific and practical interest is primarily represented by technologies: "Digital Twin", "Technologies of Virtual and Augmented Reality", "Robotics and Sensorics". To measure the concentrations of individual chemical ingredients of pollution in the aerodrome area, as shown by numerous studies, sensors based on various physical principles are used. It is not always technically and technologically possible to perform control and measurement operations at various points of a spatial model, therefore, in this study, it is proposed to use unmanned aerial vehicles equipped with the necessary sensors, technical controls and communication with the Center for Environmental Control [22].

Based on the analysis of technical and economic indicators given by digital technologies, a structural and functional model for managing the quality of the air environment in the area of the Almaty airport was developed, which is shown in Figure 1. aerodrome space by 3-dimensional sounding of the object by eight chemical ingredients.

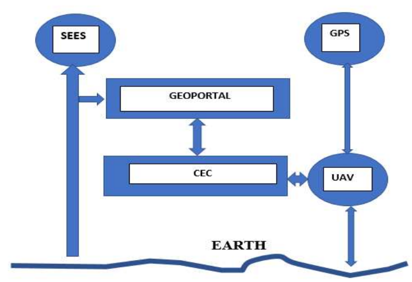

Figure 1: Functional and technological model of the airfield atmosphere quality monitoring system in Almaty

Figure 1 illustrates the following agents of the system: remote sensing - satellite earth sensing system, GPS - space-based object positioning system, UAV - unmanned aerial vehicle, geoportal - State system of space monitoring of the earth's surface, CEC - Center for environmental control of the airport in Almaty).

The model presented in Figure 1 shows the connection of the environmental service of the CEC airport with the national system of environmental monitoring. The proposed model provides for the

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possibility of studying the airspace within the given geometric boundaries in three dimensions, as well as in vertical and horizontal spatial planes at the operator's choice and obtaining the necessary information slice.

The first task in working with 3D models of the space under study is to substantiate the geometric shape of the object under study. The real physical model of spatial concentration and territorial distribution of pollution ingredients does not have a clear geometric shape, which poses the problem of choosing control points, greatly complicates the process of controlling the flight path of an unmanned vehicle and increases the complexity of control. The use of an unmanned vehicle greatly simplifies the solution of this problem and improves the manufacturability of control, both in the horizontal control plane and in the vertical section of the spatial model. The use of an unmanned vehicle in such an application opens up completely new perspectives. These devices can be used in the monitoring system in several modes of spatial positioning: manual control mode; automated program control mode. The drone control mode is selected depending on the purpose and tasks that are solved in a particular case. The analysis and preliminary calculations have shown that the geometric 3D model of the virtual space will be technologically optimal in the form of a cylinder. The shape of the cylinder greatly simplifies both manual control of the drone and automated programmable mode. Then, taking into account all the initial restrictions, the model will be a virtual spatial-informational atmospheric "cylinder", which is shown in Figure 2.

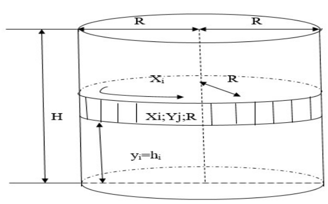

Figure 2: Virtual spatial information model of the atmospheric 3D object of air pollution

The three-dimensional point Xi;Yj;R is a spatial coordinate in the volume of the virtual cylinder. The parameter R is the radius of the cylinder. The parameter H is the height of the cylinder. Parameter hj is the height of the j-th horizontal information slice. The outer side surface of the cylinder with area $S=2\pi R\times H$ is a two-dimensional array of measurement data of the pollution components along the radial (lateral) surface of the cylinder. The information matrix of the data of this surface will look like this (Fig. 3).

$\{X_{n,1}\}$	$\{X_{n,2}\}$	....	......	....	$\{X_{n,m}\}$
....	....	....	....	....	....
....	....	....	......	....	....
....	....	......	....	....	......
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	......
....	....	....	....	......	....
$\{X_{1,1}\}$	$\{X_{1,2}\}$	......	.....	....	$\{X_{1,m}\}$

Figure 3: Array of measurement data for the values of one pollution ingredient on the radial surface of a cylinder with radius R and height H

Each element of the array contains the measurement result of a separate contamination ingredient at some point of the lateral surface of the cylinder xij. from the expression $\Delta x = 2\pi R/m$. The number of elements along the height of the cylinder is determined from the expression $\Delta h = H/n$. The operator sets the sampling steps Δx and Δh manually. The minimum value of sampling parameters is determined by the positioning accuracy of the unmanned vehicle. The number of arrays is determined by the number of controlled ingredients, in this study this value is equal to k=8. By changing the digitalization parameters Δx, Δh and ΔR, it seems possible to build in 3D a complete model of the volumetric density of atmospheric pollution in the volume of the investigated "cylinders". By varying the radius of the studied air volume, it is possible to reveal the dynamics of the spread of pollution, both in general throughout the volume, and in individual atmospheric layers and for each of the eight components of pollution. The quality of the analysis of the studied ecological atmospheric processes will increase significantly if the results of the research are presented in a three-dimensional format.

4.2 Development of an integral criterion for assessing air quality in the controlled area of the airport.

Due to the fact that the modeling of atmospheric quality control processes is carried out under conditions of parametric fuzziness of control agents and statistical uncertainty of modeling data, the theory of fuzzy sets was chosen as a mathematical apparatus for searching for a model for integrated assessment of the quality of the atmospheric environment [23, 24]. Fuzzy models and algorithms operate with the so-called linguistic variables and terms. A linguistic variable in the field of a quantitative vector is represented by model elements of fuzziness, called "terms". Each term in

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the linguistic field has some "weight" in the environment of a particular linguistic variable. The weight of a linguistic variable is also determined by the method of expert evaluation since the use of analytical methods in this methodology is not possible. Each linguistic variable is expertly assessed with the assignment of a "weight", which will be the coefficient of significance of the above ingredients of the air near the aerodrome environment of the airport in Almaty. The results of the expert analysis are shown in Table 1. A graphical interpretation of the process of forming an integrated criterion for the quality of the near-aerodrome environment on a fuzzy approach is shown in Figures 4-12.

Table 1 - The results of an expert analysis of the significance of the components of air pollution in the aerodrome environment of the airport in Almaty.

Variant number	Expert weight	Atmospheric pollution							
		NO	CO	CO_2	SO_2	H_2S	NO_2	O_3	NH_3
1	5,8	0,214	0,085	0,057	0,128	0,1	0,2	0,171	0,042
2	5,4	0,144	0,043	0,101	0,217	0,15	0,086	0,188	0,057
3	6	0,129	0,096	0,064	0,225	0,145	0,177	0,048	0,112
4	7,8	0,223	0,089	0,059	0,149	0,134	0,179	0,044	0,119
5	6	0,142	0,158	0,047	0,111	0,079	0,190	0,238	0,031
Arithmetic mean		0,174	0,095	0,065	0,164	0,123	0,168	0,131	0,076
Ingredient Grade		1	6	8	3	5	2	4	7

The hazard level of atmospheric pollution is divided into four zones in percent, where each zone corresponds to a certain term with a weight coefficient: ω_1 - low-hazard; ω_2 – moderately dangerous; ω_3 – highly dangerous; ω4 – extremely dangerous. Then graphically fuzzy models will have the following form.

К1 – Linguistic variable K1 – NO

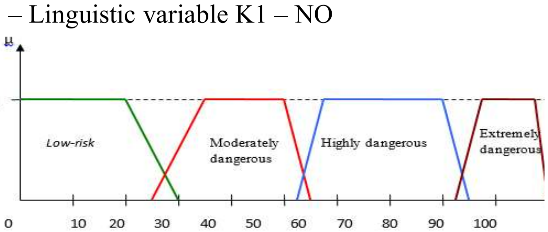

Figure 4. NO pollution level

Fuzzy linguistic models for CO, CO_2, NO_2, SO_2, H_2S, O_3 NH_3 are constructed similarly.

The following analytical expressions for fuzzification are recommended:

$$MF(x) = \begin{cases} 1 - \dfrac{b-x}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ 1 - \dfrac{x-c}{d-c}, & c \leq x \leq d \\ 0, in\ other\ cases \end{cases}$$

where a, b, c, d - are trapezoid parameters.

For further calculations, the weight of the above terms is revealed, the values of which are presented in Table 2.

Table 2 - Weights of terms

Name of Contamination Ingredient (linguistic variable Y_i)	Weight ling. variable (ω_i)	Terms weight			
		λ 1	λ 2	λ 3	λ 4
1. NO pollution level	0,136	0,094	0,166	0,178	0,270
2. CO pollution level	0,119	0,265	0,305	0,135	0,186
3 CO_2 pollution level	0.23	0,202	0,252	0,235	0,309
4. SO_2 pollution level	0,117	0,221	0,272	0,245	0,2609
5. H_2S pollution level	0,115	0,243	0,241	0,286	0,228
6. NO_2 pollution level	0,272	0,305	0,119	0.239	0,265
7. O_3 pollution level	0.24	0,096	0,231	0,332	0,339
8. NH_3 pollution level	0,109	0,103	0,242	0,328	0,324

The physical value of the contamination ingredient is recorded by sensors and simultaneously transformed into a percentage value in relation to the maximum permissible concentrations of the ingredient. The percentage goes to pre-processing, where fuzzification is carried out, and the fuzzy value of the linguistic variable is determined by the formula:

$$y_i = \omega i \left[\frac{\sum_{j=1}^{N_j} x_{ij} \cdot \alpha_{ij}}{\sum_{j=1}^{N_j} \alpha_{ij}} \right] \quad (1)$$

where y_i is the current quantitative fuzzy normalized estimate of the i-th pollution ingredient;

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ω_i - the weight of the i-th linguistic variable determined by the expert method;
x_{ij} - current j-th value of the i-th linguistic variable as a percentage in relation to the maximum allowable concentrations.
For calculations according to formula (1), the quantitative and qualitative characteristics of linguistic variables and terms are presented in Table 2. Computational procedures for the preliminary stage of processing control data are carried out by the Arduino Rasberi P_i using a software application that implements a neural model [31]. In this case, the neural model plays the role of an integral functional for eight inputs. This neural model in the current digital atmosphere quality control system is implemented as a software module. The integrated fuzzy assessment of the quality of the controlled air environment Q is evaluated in the operational version according to the accumulated data for a certain period at the Environmental Control Center at the airport in Almaty. Quantitative fuzzy assessment of Q does not give a qualitative representation to the decision maker in the established normative verbal form. This task is the last step in the formal processing of monitoring data on the ecological state of the controlled area, in this case, the near-aerodrome habitat. This problem is solved by using the so-called desirability scale [32], [33]. With the help of inverse transformations, it is also possible to solve the problem of determining the value of the indicator that provides the predicted quality value.

4.3 Development of models for quantitative assessment of the risks of monitoring the components of atmospheric pollution.

The object of research in this case is the air quality control system in the aerodrome area of Almaty. The quality of the controlled near-aerodrome environment is assessed promptly around the clock according to the established technological schedule with specified time intervals between control sessions. Control data in absolute physical format, and after preliminary statistical processing, in the form of distribution functions are accumulated in the common database "Big Data", which is provided for by the monitoring system in digital transformation technology. The measurement result is represented by the value S_{meas}. The measured value S_{meas} in the on-board computer system of the unmanned aerial vehicle is compared with the standards, and after a preliminary analysis, the on-board logic sends the result to the “pass” channel or to the “fail” channel. The next stage of complex in-depth processing is carried out at the Center for Environmental Control under stationary conditions.
In the Center for Environmental Control, the management process is transferred to the "Digital Twin" system. Control, as noted above, contains at least three operations: measurement, comparison of the measurement result with the standard, decision-making. The quality of control is a function of many factors and parameters that are of a statistical nature, which leads to control errors (control risks). To calculate control risks, several studies offer analytical expressions and simulation algorithms in the form of probabilistic and simulation models [13,3,33]. As a result of computer modeling, it was revealed that control risks are only partially assessed by the accuracy parameters of measuring instruments, but to a greater extent depend on combinations of statistical and normative characteristics of control and decision-making agents. In well-known works, only some compositions of the control agents characteristics were studied. In [13], a study was conducted to identify the total number of possible hypothetical combinations and combinations of initial conditions in similar modeling problems. As a result of the analysis and calculation, it was found that the total number of all possible compositions of control agents and statistical laws for only one controlled indicator will be 729 combinations. Each combination of distribution laws is described by a specific mathematical or simulation model. The choice of distribution laws is determined by a specific practical task and are determined experimentally.
In well-known works, probabilistic models were proposed with a one-sided lower limit of the controlled parameter, and the case of tolerance normalization. For the quantitative control of the ingredients of air pollution, the upper maximum permissible norms of air pollution are generally accepted. In this paper, the first modeling option will be considered the case of a single-limit limitation of the controlled parameter “from below” by the standard S_n. This case of normalization is typical for the normalization of the integral assessment of the quality of control.
From a probabilistic point of view, two events are of interest in the control process:
- the actual value of the parameter is above the standard ($S_i>S_n$), i.e., the controlled parameter is normal (good), and the measured value S_{imeas}, as a result of a random error, turned out to be below the standard ($S_{imeas}<S_n$) (not good), which is a false defect;

- the actual value of the parameter is below the standard ($S_i<S_n$), i.e., the controlled parameter is in the "failed" field, and the measured value, because of a random error, turned out to be higher than the standard ($S_{imeas}>S_n$) (good), which is undetected defect.

In such situations, it becomes necessary to develop models that allow us to quantify the probabilities of both risk cases as a function of the statistical characteristics that were given above. The need for a quantitative assessment of these probable risks is dictated by the fact that it is the risks that lead to subsequent economic losses and even disasters.

The case of the lower limit of the controlled parameter in the environmental control system arises during the formal assessment of integral quality indicators. At the first stage of modeling, a hypothesis is put forward for the normal distribution of all parameters and indicators of the control process. The following notation will be used in analytical expressions: f(S) is the distribution density function of the measured parameter; S_{aver} - arithmetic mean value of the measured parameter; σ_s is the standard deviation of the distribution of the measured parameter; φ(Y) - density function of measurement error (uncertainty); σ_φ is the standard deviation of the measurement error.

Then, the statistical distribution laws will have the following analytical form:

$$f(S) = \frac{1}{\sigma_S\sqrt{2\pi}} \cdot e^{-\frac{(S_i - S_{aver})^2}{2\sigma_S^2}}; \qquad \varphi(Y) = \frac{1}{\sigma_\varphi\sqrt{2\pi}} \cdot e^{-\frac{Y^2}{2\sigma_\varphi^2}}$$

n the modeling process, it can be called an event A - a situation in which the actual value of S_i lies in a certain range of values S_i S_{i+1}, i.e., the parameter is in the standard zone. The probable event B is that the instrument reading is beyond the limiting threshold of parameter values, which will be called and interpreted as a false defect. Then the probability of the simultaneous occurrence of these events P_{ifd} can be estimated from the expression:

$$P_{ifd} = \int_{S_i}^{S_{i+1}} f(S)dS \cdot \int_{-\infty}^{S_i - S_n} \varphi(Y)dY \quad (2)$$

In practice, expression (2), by passing to a new integration variable t, measures the parameters not in absolute values, but in standard deviations. Then the final expression for P_{fd} will look like:

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

In a similar way, an expression is found for estimating an undiscovered defect P_{ud}, which will have the form:

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

The next task is to study the influence of the statistical properties of marginal standards on the reliability and risks in the control system. In the previous tasks of formalizing the processes of control and forecasting risks, a hypothesis was put forward about the determinism of the lower and upper standards. At the same time, practice shows that there are many external and internal factors that affect the uncertainty of regulations. Attention is drawn to this real fact in many works [13, 34]. Uncertainty is difficult to measure; it is usually assessed qualitatively, for example, "more or less, higher or lower". Under the conditions of statistical uncertainty, as applied to the decision-making system, the uncertainty can be estimated by the coefficient of variation of the controlled parameter [35]. Uncertainty is the main cause of control errors. Hence, it is legitimate to put forward a hypothesis that the limiting values of the controlled parameter are random values, subject to certain statistical distribution laws in each specific case.

Then, the statement of the problem under the hypothetical assumptions made will be as follows: to develop a model for assessing and predicting the risks of control in the conditions of the non-deterministic nature of the standards.

As the first example, the paper considers the case of a normal distribution of a controlled parameter, a normal distribution of a random error, and a normal distribution of a standard value with a "top" constraint.

It is assumed that the distribution density function of the normative value has the form:

$$\theta(S_n) = \frac{1}{\sqrt{2\pi}\sigma_n} e^{-\frac{(S_n - S_{naver})^2}{2\sigma_n^2}}$$

where σ_n - is the standard deviation of the normative value distribution law;

S_{naver} - is the average value of the standard.

Then out of the total number of controlled objects N, the probable number of objects N_i having the i-th normative value will be:

$$N_i = P_i \cdot N = N \int_{S_{naver-3\sigma_n+j\Delta S_n}}^{S_{naver-3\sigma_n+(j+1)\Delta S_n}} \theta(S)dS$$

where $\Delta Sn = \frac{3\sigma_n}{m}$

The probability P_{fd} for the i-th value of the standard S_n and the j-th value of the parameter S has the following form:

$$P_{ijfd} = \frac{1}{\sqrt{2\pi}}\int_{M_i}^{D_i} e^{-\frac{t^2}{2}}dt \cdot \frac{1}{\sqrt{2\pi}}\int_{\frac{3k-j}{k}}^{3} e^{-\frac{z^2}{2}}dz$$

$$M_i = \frac{S_{ni}-S_{aver}}{\sigma_S} + \frac{3(j-k)}{k}; \qquad D_i = \frac{S_{ni}-S_{aver}}{\sigma_S} + \frac{3(j+1-k)}{k}$$

$$\Delta S = \frac{3\sigma_S}{k}$$

The total probability P_{fd} for the limit S_{ni} is:

$$\left(P_{fd}\right)_i = \sum_{j=0}^{k}\left(P_{jfd}\right)_i \sum_{j=0}^{k} \frac{1}{\sqrt{2\pi}}\int_{M_i}^{D_i} e^{-\frac{t^2}{2}}dt \cdot \frac{1}{\sqrt{2\pi}}\int_{\frac{3k-j}{k}}^{3} e^{-\frac{z^2}{2}}dz$$

The probable number of erroneous defects from the population N_i will be equal to:

$$N_{ifd} = N_i\left(P_{fd}\right)_i$$

The probable number of objects erroneously rejected from the entire sample N is expressed by the formula:

$$N_{fd} = \sum_{i=0}^{m} N \int_{L_i}^{H_i} \theta(S_n)dS_n \left[\sum_{j=0}^{k} \frac{1}{\sqrt{2\pi}}\int_{\theta_i}^{\lambda_i} e^{-\frac{t^2}{2}}dt \cdot \frac{1}{\sqrt{2\pi}}\int_{\frac{3j}{k}}^{3} e^{-\frac{z^2}{2}}dt\right]$$

$$\theta_i = \frac{S_{ni}-S_{aver}}{\sigma_n} + \frac{3j}{k}; \qquad H\lambda_i = \frac{S_{ni}-S_{aver}}{\sigma_n} + \frac{3(j+1)}{k}$$

For the case of the distribution of normative values S_n according to the normal law, and the controlled parameter S according to the Weibull law, there will be the following logic of reasoning and conclusions. The distribution density function of the Weibull law has the following form:

$$f(S,\alpha,\beta,\gamma) = \frac{\beta}{\alpha}(S-\gamma)^{\beta-1}e^{-\frac{(S-\gamma)^\beta}{\alpha}}, \quad S \geq \gamma$$

where α - scale parameter;
β - form parameter;
γ - position parameter.
In the case of using the Weibull law, one can use its integral form, which has the form:

$$F(S) = 1 - e^{-\frac{(S-\gamma)^\beta}{\alpha}}$$

With a one-limit parameter restriction, the value of the false defect probability P_{lbi} has the following mathematical expression:

$$P_{fdi} = \sum_{j=0}^{k} P_{(jfd)i} = \sum_{j=0}^{k}\left[exp\left(-\frac{S_i^\beta}{\alpha}\right) - exp\left(-\frac{S_{i+1}^\beta}{\alpha}\right)\right]\frac{1}{\sqrt{2\pi}}\int_{\frac{S_{ni}-S_j}{\sigma_\varphi}}^{+3} e^{-\frac{z^2}{2}}dz$$

The total number of falsely rejected results from sample N will be:

$$N_{fd} = \sum_{i=0}^{m}(\Delta N_i) = \left(N\int_{L_i}^{H_i}\theta(S)dS\right) \cdot \sum_{j=0}^{k}\left[exp\left(-\frac{S_i^\beta}{\alpha}\right) - exp\left(-\frac{S_{i+1}^\beta}{\alpha}\right)\right] \cdot \frac{1}{\sqrt{2\pi}}\int_{\frac{S_i-S_j}{\sigma\varphi}}^{+3} e^{-\frac{z^2}{2}}dz \qquad (3)$$

For the case of an undetected number of defects from the sample N will be:

$$N_{ud} = \sum_{i=0}^{m}\left(N\int_{L_i}^{H_i}\theta(S)dS\right) \cdot \sum_{j=0}^{k}\left[exp\left(-\frac{S_i^\beta}{\alpha}\right) - exp\left(-\frac{S_{i+1}^\beta}{\alpha}\right)\right] \cdot \frac{1}{\sqrt{2\pi}}\int_{\frac{3-\Delta S}{\sigma\varphi}}^{+3} e^{-\frac{z^2}{2}}dz$$

(4)

The reliability of control is found from the expression:

$$D = 1 - \left(P_{fd} + P_{ud}\right)$$

Analytic expressions (3, 4) are implemented as software applications.

5. RESULTS OF A COMPUTER EXPERIMENT.

To implement the goal and objectives of the study in practice in real conditions, developments were carried out to improve the methods and instrumental support of the atmospheric technogenic pollution control system, experimental and statistical field studies and computer modeling based on theoretical and statistical studies. As a result of experimental studies, a new system was developed for differential measurement of the concentrations of individual air pollution ingredients in a local geometrically limited air-controlled space, which is represented, as described above, in the form of an atmospheric cylinder. The structural model of such a control system is shown in Figure 5. The metrological indicators of air pollution control based on this model were studied using the example of control of nitrogen dioxide NO_2, as the most dangerous substance for health.

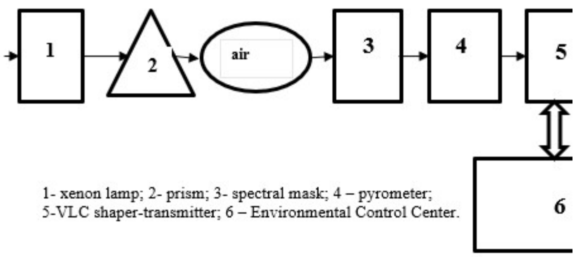

Figure 5: O_3 pollution level

In Figure 5, the xenon lamp 1 provides a wide spectrum of radiation. The continuous spectrum of the lamp is directed to prism 2, which decomposes and converts the continuous spectrum into a discrete line spectrum. The discrete spectrum through the air medium of a special air intake enters the spectral mask 3, where a window is provided for the spectral component of NO_2. The intensity of the spectral component of NO_2 is converted by pyrometer 4 (MG 30) into electric current. The appearance of the pyrometer is shown in Figure 13. The electrical signal from the pyrometer, which has a built-in voltage amplifier, is fed to the VLC 5 block. This block contains a DC voltage converter from the pyrometer 4 output into a pulse-width code sequence.

The VLC (Visible Light Communication) technology provides communication over visible light and allows the light source to be used as a means of transmitting information [33]. The pulse-width code sequence is the supply voltage of the LED light source, which is registered by a photodetector at 500m located in the territory of the environmental control center 6. The advantage of VLC technology is high information security. Block 5 also contains white light LEDs and infrared LEDs, which provides duplication of information exchange.

In the organizational and technical structural block 6, the final processing, analysis of the results of monitoring the ecological state of the observation object and the construction of a virtual model of the NO_2 content digital twin in the controlled space are carried out. The virtual model of the digital twin is a “cylinder” of NO_2 control data in natural physical measurable format (mg/m^3).

For the practical use of the new NO_2 measurement method (Fig. 5), testing of this method is required. For this purpose, an AR 520 spectrometer with ultraviolet and infrared detectors installed in it was used. Testing was carried out in laboratory conditions using the example of measuring NO_2 in the exhaust gases of a diesel engine. The measurement results of the AR 520 spectrometer were compared with the results of the proposed method. Correlation analysis of the measurement results with the AR 520 spectrometer and the results of the proposed method showed that the linear correlation coefficient is R=0.87. According to the Chaddock scale, a qualitative assessment of the degree of statistical connection of the studied data allows us to consider this connection as “high”, which mathematically confirms the metrological quality of the new method and the possibility of its use in practice.

Experimental studies of NO_2 content in real conditions were carried out on the territory of a thermal power plant, which is the dominant source of pollution of adjacent urban areas. The measuring equipment was placed on a UAV with a payload capacity of 20 kg. The system for receiving and processing data in the VLC format was placed on a special vehicle. The results of NO_2 measurements using the new control method are shown in Table 3.

Table 3. NO_2 measurement results

Height (Hi m.)	The value of NO_2 (mg/m^3) in the i-th controlled area along the perimeter of the atmospheric "cylinder" with a step of 100m. (L_j)					
	L_1	L_2	L_3	L_4	L_5	L_6
10	22.3	20.4	20.1	22.1	22.1	21.3
20	18.4	19.1	18.6	19.4	17.4	17.4
30	17.3	16.3	17.8	18.4	18.3	18.3
40	17.8	17.1	17.2	17.2	17.4	17.4
50	16.2	16.8	16.5	16.1	16.6	16.7
60	16.1	16.2	16.2	16.3	16.2	16.4
70	14.8	14.3	14.4	14.4	14.7	14.2
80	14.2	14.1	14.5	14.5	14.7	14.1
100	15.1	15.3	14.3	13.2	15.2	15.6

Statistical software package Statistica 6.0 was used for statistical processing of data in Table 3. As a result of statistical processing, the arithmetic means X_{av} = 17.4 mg/m^3 and the standard deviation S= 1.38

mg/m^3 were found. The closest hypothesis about the theoretical law of distribution is the Gauss law.
Using statistical processing data and a software application implementing the mathematical software developed above to calculate the risks of control, it was found that the probability of the risk of undetected defect is equal to R_{ud} = 0.23, the probability of the risk of false defect R_{fd} = 0.112.
Based on experimental and statistical studies, it should be concluded that control risks are indicators of augmented reality, since physically real measuring instruments are used, but the entire control process operates and integrates uncertainties such as: statistical properties of the controlled parameter and measuring instruments, uncertainty of normative values and the decision-making process. Of note is the uncertainty of standards, which by their nature and methodology of their formation cannot be deterministic values.
A computer experiment was implemented to identify the integral effective relationship between control agents under the conditions of statistical uncertainty of environmental monitoring.
The results of the computer experiment are interpreted in a graphical 3D format, where the argument is the error in the form of the ratio σ_{meas}/σ_s (here σ_{meas} is the measurement uncertainty; σ_s is the uncertainty of the controlled parameter). This ratio varies in the range from 0.1 to 1.0 at different values of the upper standard ($XP=S_{av}+\sigma_s$; $XP=S_{av}+2\sigma_s$; $XP=S_{av}+3\sigma_s$).
In order to visualize the overall picture of the influence of the statistical nature of the control parameters on the risk of an undetected defect PNB and the reliability D, the results of computer modeling were presented in three-dimensional interpretation in the axes:
PNB - the axis of the probability of an undetected defect - dependent variable;
D - axis of control reliability - dependent variable;
SF_SS - relative error axis - independent variable;
SPBHN - standards in shares,
σ_s - independent variable. The simulation results are illustrated in Figures 6-7.

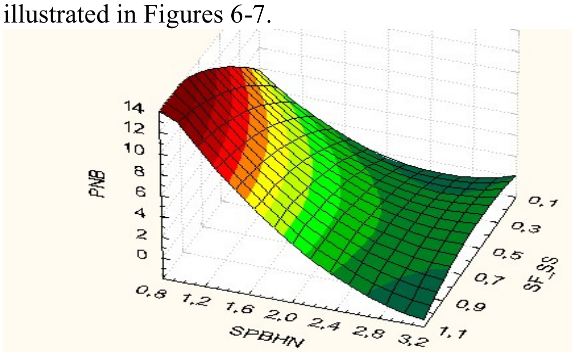

Figure 6: Graphical model of probability (risk) PNB

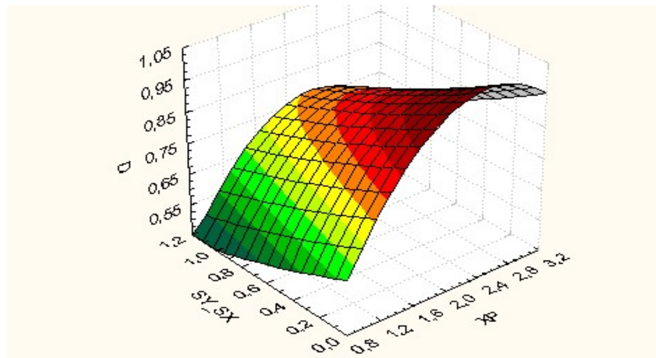

Figure 7: The dependence of the reliability of control D on the measurement error SY_SX and the standards of control XP

As follows from the 3D surfaces of risk modeling and control reliability, the results have a pronounced nonlinearity, which makes it almost impossible to use classical additive approaches to predicting the results of control and decision-making.
As a result of computer modeling, the following was also revealed:
1. The analysis of the calculated values indicates the presence of a clearly distinguished minimum contour. The line of minimum reliability of decision-making under normal laws of distribution of control parameters passes through the points 82.15%, 70.3%, 63.05%, 62.1%, 59.5% and 57.95%. This range is typical for normal laws.
2. It should be noted the general trend of decreasing statistical reliability to 58% with increasing variation, which is quite understandable from the standpoint of mathematical statistics.
3. On the confidence surface, for the case of a normal distribution of control parameters, the maximum line passes through the values 10.58%, 16.5%, 25.95%, 27.05%, 29.63%, 31.3%.

CONCLUSION.

The purpose of this study is to develop a formal approach in order to assess the reliability and risks in the airfield control system. This referred to the digital transformation of the aviation industry business. To achieve this goal, the following tasks are solved: primarily, the geometric model of controlled airspace were justified in the area of the Almaty airport. This geometric model is presented in the form of an atmospheric cylinder with a given radius and height. In addition, there was developed a functional and technological model of the airfield quality monitoring system in Almaty. This was based on the use of unmanned aerial vehicles with constant radio communication operated by environmental control center at the airport. Also, there was built a virtual-spatial information 3D model of atmospheric pollution near the aerodrome environment in the "Digital Twin" format. Therefore, a fuzzy model of an integral criterion for assessing air quality in the controlled area of the Almaty airport has been developed. Additionally, there have been developed a probabilistic models on order to assess the reliability and risks of air pollution control in the near airfield environment. This is analysed under deterministic and non-deterministic standards for the concentration of chemical ingredients in the air environment of the Almaty airport. Lastly, a computer experiment has been implemented for numerical estimation of the reliability and risks of pollution control of the near-aerodrome environment.

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REFRENCES

[1] Code of the Republic of Kazakhstan dated January 2, 2021 №. 400-V1. (in Russian), “Environmental Code of the Republic of Kazakhstan (with amendments and additions from 12/27/21) [Online]. Available: URL: https://adilet.zan.kz/rus/docs/K2100000400

[2] “On approval of the State Program "Digital Kazakhstan" (in Russian), Decree of the Government of the Republic of Kazakhstan, Dec. 12, 2017, № 827. Accessed: May 30, 2018. [Online]. Available: https://adilet.zan.kz/rus/docs/P1700000827.

[3] Russia and Kazakhstan: digital transformation. (in Russian), [Online]. Available: URL: https://news.tpprf.ru/ru/news/2363414/

[4] D. Dang-Pham, A.-P. Hoang, D.-T. Vo, and K. Kautz, “Digital Kaizen: an approach to digital transformation,” Australasian Journal of Information Systems, vol. 26, 2022, doi: 10.3127/ajis.v26i0.3851

[5] Tao, F.; Xiao, B.; Qi, Q.; Cheng, J.; Jin, P. Digital twin modeling. J. Manuf. Syst. 2022, 64, 372–389. doi: 10.1016/j.jmsy.2022.06.015

[6] Digital twin. (in English), [Online]. Available: URL: https://trends.rbc.ru/trends/industry/6107e5339a79478125166eeb

[7] Big Data - what are big data systems? Development. (in English), [Online] Available: URL: https://trends.rbc.ru/trends/innovation/5d6c020b9a7947a740fea65c

[8] K. Kováčiková, T. Remencová, A. Novák Sedláčková, A. Novák. The impact of Covid-19 on the digital transformation of the airports, Transportation Research Procedia, Volume 64, 2022, pp.84-89. [Online]. Available: URL:. https://doi.org/10.1016/j.trpro.2022.09.011.

[9] Buyul A., Zefel P. SPSS: the art of information processing. Analysis of statistical data and restoration of hidden patterns. 2001., ISBN: 5-93772-032-6 Moscow: DiaSoft, p.608.

[10] Paweł Głowacki, Piotr Kalina, Michal Kawalec., Estimating Emissions of Harmful Exhaust Components by Aircraft Engines During the Takeoff and Landing Cycle in Airport Space., Transactions on Aerospace Research., Volume 2(261) 2021., pp.63-70. doi: https://doi.org/10.2478/tar-2021-0011

[11] Haktanır, E., Kahraman, C., Şeker, Ş., Doğan, O., Future of Digital Transformation. In: Kahraman, C., Haktanır, E. (eds) Intelligent Systems in Digital Transformation. Lecture Notes in Networks and Systems, vol 549, 2022. Springer, Cham. [Online] Available: URL: . https://doi.org/10.1007/978-3-031-16598-6_26

[12] Gribanov Yu.I., 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, 2019. [Online] Available: URL: https://unecon.ru/sites/default/files/dissgribanovui.pdf

[13] Graham, W. R., Hall, C. A. & Vera Morales, M. The potential of future aircraft technology for noise and pollutant emissions reduction.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Transp. Policy 34, 2014 pp.36–51 . doi: 10.1016/j.tranpol.2014.02.017

[14] Selcuk Ekici, Gorkem Yalin, Onder Altuntas, Hikmet Karakoc, Calculation of HC, CO and NO_x from civil aviation in Turkey in 2012. Int. J. Environment and Pollution, Vol. 53, № ¾

[15] X. Liu, Y. Bao, Y. Zhang and J. Li, "Decoupling analysis on China's civil aviation carbon emissions from transportation revenue: A three-dimension decomposition framework", Sustain. Prod. Consumption, vol. 32, pp.718-730, Jul. 2022. doi: 10.1016/j.spc.2022.05.023

[16] V. A. Miyagasheva, D. R. Inshakov, A. V. Ponomarev, O. G. Boyko. Ecological problems in aviation and solutions. Current problems of aviation and space - 2016. Volume 1

[17] Harley G, Timmis A, Budd L. Factors affecting environmental practice adoption at small European airports: An investigation. Transp Res D Transp Environ. 2020., №88:102572. doi: 10.1016/j.trd.2020.102572.

[18] Kanke A.A., Eremina T.N. Educational ecosystem in conditions of digital transformation. E-Management. 2022; 5(4):31-38. doi: https://doi.org/10.26425/2658-3445-2022-5-4-31-38

[19] The metaverse. What is it, and which metaverse is bette. (in English), [Online] Available: URL: https://ru-crypto.com/metaverse

[20] João Reis, Marlene Amorim, Nuno Melão & Patrícia Matos, «Digital Transformation: A Literature Review and Guidelines for Future Research», In book March 2018., pp.411-421, doi:10.1007/978-3-319-77703-0_41.

[21] João Reis, Marlene Amorim, Nuno Melão, Yuval Cohen & Mário Rodrigues, «Digitalization: A Literature Review and Research Agenda», 21 March 2020., pp 443–456

[22] Zhang, H.J.; Yan, Q.; Wen, Z.H. Information modeling for cyber-physical production system based on digital twin and Automation ML. Int. J. Adv. Manuf. Technol. 2020 107, 1927–1945. doi: 10.1007/s00170-020-05056-9

[23] M. Alenezi, "Ontology-based context-sensitive software security knowledge management modeling," International Journal of Electrical and Computer Engineering (IJECE), vol. 10, no. 6, pp. 6507–6520, 2020, doi: 10.11591/ijece. v10i6.pp6507-6520.

[24] Zadeh, Lotfi. Outline of a New Approach to the Analysis of Complex Systems and Decision Processes / IEEE Transactions on Systems, Man, and Cybernetics, SMC-3(1), January 1973,pp.28-44.

[25] M. Alenezi, "Ontology-based context-sensitive software security knowledge management modeling," International Journal of Electrical and Computer Engineering (IJECE), vol. 10, no. 6, pp. 6507–6520, 2020, doi: 10.11591/ijece. v10i6.pp6507-6520.

[26] T. Aksoy, S. Yüksel, H. Dınçer, U. Hacioglu and R. Maialeh, "Complex Fuzzy Assessment of Green Flight Activity Investments for Sustainable Aviation Industry," in IEEE Access, vol. 10, pp. 127297-127312, 2022, doi: 10.1109/ACCESS.2022.3226584.

[27] Yurchuk, A. P. Influence of aviation on the environment and measures to mitigate the negative impact / A. P. Yurchuk. - Text: direct // Young scientist. - 2021. - No. 8 (350). pp.198-201. [Online] Available: URL: https://moluch.ru/archive/350/78715/

[28] Atmospheric air quality criteria//https://vtorothodi.ru/ecology/normirovanie-kachestva-atmosfernogo-vozduxa(date of appeal - 09.12.2022)

[29] Lynnette Dray. An analysis of the impact of aircraft lifecycles on aviation emissions mitigation policies. Journal of Air Transport Management, Volume 28, 2013, pp. 62-69, doi: https://doi.org/10.1016/j.jairtraman.2012.12.012

[30] Air quality indicators., [Online] Available: URL: https://studref.com/399960/ekologiya/

[31] Yin, Z. H., & Wang, L., Application and development prospect of digital twin technology in aerospace application and development prospect of digital twin technology in aerospace. IFAC PapersOnLine, 5, pp.732–737. doi: https://doi.org/10.1016/j.ifacol.2021.04.165

[32] 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

[33] Ozgur Balli. Life cycle assessment and exergoenvironmental analyses for making a decision in the fuel selection for aero-engines: An application for a medium-size turboprop engine (m-TPE), Energy Conversion and Management, Volume 266, 2022, doi: https://doi.org/10.1016/j.enconman.2022.115813

[34] Radjabov R.K. Modeling of microeconomics: - Dushanbe: "Irfon", 2017. ISBN 978-99975-0-740-2. pp. 16-31

[35] La, J., & Heiets, I. (2021). The impact of digitalization and intelligentization on air transportation system. Aviation, 25(3), pp.159-170. doi: https://doi.org/10.3846/aviation.2021.15336