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Model of the process safety management system at an airline

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Abstract: The purpose of the process safety management system is to identify hazard factors and develop a set of methods to prevent injuries at an airline, occupational illness, material costs in case of damage to property and the environment. The analysis of the structure of occupational pathology depending on the factors of the production environment and the working process for the period 2013–2022 shows that the percentage of diseases associated with the impact of production physical factors for this period remains at the same level. This fact, in turn, confirms the relevance of the chosen study. Analysis and identification of the current production situation is necessary to assess the impact of adverse production factors. In this study, a new approach to the mathematical model for a process safety management system is implemented. Mathematical modeling allows a deeper understanding of the nature of certain phenomena and to obtain information about the real situation, which in turn stimulates the development of new scientific problems and methods of solving them, and is also the basis for choosing specific solutions for the implementation of certain projects. The successful implementation of strategies in order to create a process safety system for a flexible monitoring and management structure depends on how effective its functional structure is; this provision is explained by the fundamental nature of the tasks that are solved at the management stage. The article discusses the theoretical statements concerning mathematical modeling. When creating the model, the apparatus of abstract algebra-set theory – was used. The model developed in the course of the study makes it possible to introduce a model of the process safety management system into the activities of aviation enterprises.

Key words: mathematical model, process safety, system concept, set theory, management, model operation.

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Модель системы управления производственной безопасностью на авиапредприятии

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Аннотация: Целью системы управления производственной безопасностью является выявление факторов опасностей и разработка совокупности методов для предупреждения травматизма на авиапредприятии, профессиональной заболеваемости, материальных затрат в случае ущерба имуществу и окружающей среде. В ходе анализа структуры профессиональной патологии в зависимости от воздействующих факторов производственной среды и трудового процесса за период 2013–2022 годов показано, что процент заболеваний, связанных с воздействием производственных физических факторов, за данный период остается на прежнем уровне. Данный факт в свою очередь подтверждает актуальность области выбранного исследования. Анализ и выявление складывающейся производственной обстановки необходим для проведения оценки влияния неблагоприятных производственных факторов. В данном исследовании реализован новый подход к построению модели для системы управления производственной безопасностью. Математическое моделирование позволяет более глубоко понять природу некоторых явлений и выявить ту информацию, которая отражает реальную ситуацию и является фактором, стимулирующим развитие новых научных проблем и способов их решения, а также основой для принятия конкретных решений при реализации определенных проектов. Успешное осуществление стратегий в целях создания системы производственной безопасности для гибкой структуры мониторинга и управления неотъемлемо зависит от того, насколько эффективна ее функциональная структура, данное положение объясняется фундаментальностью задач, которые решаются на этапе управления. В статье рассмотрены теоретические положения, касающиеся математического моделирования. При создании модели был использован аппарат абстрактной алгебры – теория множеств. Разработанный в ходе исследования подход дает возможность ввести модель системы управления производственной безопасностью в деятельность авиапредприятий.

Ключевые слова: математическая модель, производственная безопасность, системный подход, теория множеств, управление, моделирование.

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Introduction

Airport employees are exposed to different hazard factors, such as noize, vibration, electromagnetic fields, nuclear radiation, and other ones affecting their health and working capacity during air transportation. It is necessary to take measures to reduce the effect of this factors and provide the safe labour conditions [1] in order to prevent workers from undesirable effects for their health.

The analysis of occupational pathology structure in Russia dependant on the production environment influencing factor showed that diseases, directly connected with physical factors affecting health of workers take the first place, representing a respective proportion of 47% in 2022. The following figure is 5% more than the same one in 2021 (42%) and 0.5% more than the one in 2013 (46.5%)[1].

Process safety management is an utter system of arrangements and technical means, necessary for hazard factors affect probability reduction for airline employees, along with manifestation consequences elimination [2].

The process safety management service uses different sources (such as scientific and technical and economic data), presented both as scientific research works, patents, standards, handbooks and descriptions of the inventions for the information analysis. As a result, there is the feasibility study created for the project, which is the basis of system development. The feedback data allows to specify the particular sub-systems and estimate their interaction efficiency [3, 4].

The duration of the given stage could have been less long-term, provided field test being substituted with process system modelling. Field tests are very efficient indeed, nevertheless they also have some drawbacks, such as high labour intensity, complexity and expenditure of time and effort. On the other hand, analytical approaches possess such benefits, as efficiency and high data processing rate, as they are based on powerful computer system application. At the same time the mathematical modelling of genuine manufacturing processes is necessary for their implementation. The fact of different system functional or structural resemblance is the basis of the modelling [5].

Research methods and methodology

Mathematical modelling – is a method of different objects, processes and systems research by means mathematical models.

Mathematical modelling allows to research object and process features without the necessity of running the experiment, which may singnificantly decrease cost and time expenses for research. Besides that, mathematical models allow us to study objects and processes in different work environment and modes, which is also not always possible while conducting the experiment [6].

Mathematical model is a system of equations or inequations, describing interconnections between different parameters and variables, characterizing the object of study. Another modelling benefit is the opportunity of system parameters change in order to study their impact on results. This allows us to understand more clearly how different factors influence the system, and to choose its optimal working parameters [7].

[1] On sanitary and epidemiological welfare Condition in the Russian Federation in 2022: National Report. Moscow: Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing (2023). 368 p.

It is necessary to stick to the system approach while monitoring and managing the manufacturing processes at an airline, considering that all objects and processes, connected with process safety system characteristics saving and enhancing with different factors exposure are to be regarded as integrated system. Processes of manufacturing system condition control, estimation and management as a whole [8] are the elements of monitoring and management system.

It is necessary to use the models showing all the system work and element interconnection aspects during the preparation stage of making the system for efficient decision making. The hierarchical system of various abstraction level modelling meets the given requirements.

The recovery process modelling includes making a model which describes the interconnection between system elements. Processes may be presented as the change of the system condition under the impact of different factors, influencing various system features and its relations with other elements [9].

The management processes in aviation manufacturing system have their own peculiarities, due to which it is impossible to use the basic principle of new management system modelling – a method of analogies.

The choice of the most efficient management methods and their optimal sequence determination requires a special approach. One can imagine system management process in general as a sequence of the following stages:

- aims and objectives determination: system management aims and objectives are formulated at this stage;
- data collection and analysis: data on system condition is collected, its analysis is run for challenges and opportunities determination;
- management strategy development: the analysis-based strategy is developed;
- strategy implementation: the arrangements are made for achieving the goal, the performance is controlled;
- monitoring and control: control is provided during the system operation;
- the analyses and evaluation of the results: the results obtained are analyzed and the management efficiency is estimated.

Such a description of the system structure allows us to determine the requirements for correspondences and formalize them in terms of system recovery process system [10].

The above-mentioned theories are materialized in mathematical model of process safety management and characteristics, lost under different factor impact, recovery. The following model uses the theory of multitudes [11] – the instrument of abstract algebra.

The initial system is qualitative, if all its elements and connections between them meet the requirements. Every element of such as system is described by the qualimetric [12] figure of it a_i:

$$a_1, \dots, a_2, \dots, a_j, \dots, a_n.$$

The n total of qualimetric quality measures united ∩ into A multitude is to be considered as a model of process system element in multitude algebra terms. The power of this total equals to quantity of singular measures, determined in different documents (for instance, public health regulations):

$$\mathrm{A} = \bigcup_{i=1}^{n} a_i. \quad (1)$$

In this case A – is a multitude, uniting quality measures a_i, which means $a_i \in A$ and whether any quality measure meets the singular $i \neq j$ variable it forms $a_i \cap a_j \rightarrow \varnothing$ empty set.

This approach does not require the particular modelling of every single system component. The quality of system is determined by quality of its components and their interaction peculiarities.

a_i is influenced by different b_j factors, changing singular quality measures for δa_i number during the system operation:

$$A/\Delta\mathrm{A} = \bigcup_{i=1}^{n} (a_i/\delta a_i). \quad (2)$$

The complex factor impact on process system element may be described as the factor unity:

$$B = \bigcup_{j=1}^{m} b_j. \tag{3}$$

The change of quality measures for δa_inumber is *f* function: for factors and time of their impact on the process system element:

$$f\colon\left(\bigcup_{j=1}^{m} b_j\,,\tau\right) \rightarrow \bigcup_{i=1}^{n} a_i/\delta a_i. \tag{4}$$

Let us write down (2) the following way, using formula (4):

$$A/\Delta \mathrm{A} = \bigcup_{i=1}^{n} f\colon\left(\bigcup_{j=1}^{m} b_j\,,\tau\right). \tag{5}$$

The parameter extreme deviations are given to provide safe work of the researched system:

$$A/\Delta \mathrm{A} = \bigcup_{i=1}^{n}(a_i/\delta a_i\; max). \tag{6}$$

In order to save safe work conditions considering process safety requirements and (5) and (6), there will be:

$$(A/\Delta \mathrm{A}\;\mathrm{max}) > \bigcup_{i=1}^{n} f\colon\left(\bigcup_{j=1}^{m} b_j\,,\tau\right). \tag{7}$$

Condition (7) is checked in a real-time environment while process safety monitoring at an airline:

$$(A/\Delta \mathrm{A}\;\mathrm{max}) > (A/\Delta \mathrm{A}). \tag{8}$$

The system work is to be shut down whether condition (8) is not fulfilled [13]. Then it is necessary to reveal the dangerous factors, estimate the risks and restore the system secure condition for working functions fulfillment (2). Nevertheless, there are some alterations: if monitoring is based on parameter current numbers (5), the fixed valuations, not meeting (8) condition, are determined during risk factors detection.

Risk factor detection helps to detect characteristics of system which need recovery, along with determining the scale of their difference from the ones meeting favorable process environment [14]. This allows to develop recovery process, its parameters and modes:

$$\bigcup_{i=1}^{n}(\delta a_i) = \left(\bigcup_{i=1}^{n}(a_i\;/\;\delta a_i)\right)/\left(\bigcup_{i=1}^{n} a_i\right). \tag{9}$$

Limits of parameter deviation from the initial ones are established by aviation industry regulations for process safety provision:

$$\bigcup_{i=1}^{n}(\delta a_i)\;\mathrm{max\,max}. \tag{10}$$

The emergency measures are taken whether limits are exceeded, including system operation shutdown [15]. Whether deviation does not exceed the limits, recovery measures for parameters, lost while system work, are taken.

System work seizing conditions:

$$\bigcup_{i=1}^{n}(\delta a_i) \geq \bigcup_{i=1}^{n}(\delta a_i)\;\mathrm{max\,max}. \tag{11}$$

System parameter recovery conditions:

$$\bigcup_{i=1}^{n}(\delta a_i)\;\mathrm{max\,max} \geq \bigcup_{i=1}^{n}(\delta a_i). \tag{12}$$

Similarly to (9), the system parameters, which do not need recovery, as they meet the requirements, may be written the following way:

$$\bigcap_{i=1}^{n}(\delta a_i) = \left(\bigcap_{i=1}^{n}(a_i/\delta a_i)\right)\;/\;\left(\bigcap_{i=1}^{n} a_i\right). \tag{13}$$

Shift from the state of "dangerous" object (2) to the state of "safe" (1) one should take place during the process safety system characteristics recovery; total of multitudes (2) and (1) allows to model such a shift in terms of multitude algebra:

$$\Phi : \left(\bigcup_{i=1}^{n}(a_i \,/\, \delta a_i)\right) \to \left(\bigcup_{i=1}^{n}(a_i \,/\, \delta^* a_i)\right). \quad (14)$$

The formula (14) may be reconstructed the following way, according to multitude algebra rules:

$$\Phi : \left(\bigcup_{i=1}^{n}(\delta a_i)\right) \to \left(\bigcup_{i=1}^{n}(\delta^* a_i)\right). \quad (15)$$

Formula (15) shows, that deviations appearing as a result of working factor δa_i impact, do not disappear after taking "recovery" measures Φ, but become a $(\delta^* a_i)$ value, to meet condition (7).

It is necessary to tend to such a deviation value, as $(\delta^* a_i) \to min$ during the process safety management system development. The ideal is when $(\delta^* a_i)$ is tending to zero: $\lim(\delta^* a_i) = \emptyset$.

The system element characteristics recovery is a process, which includes different operations, processes and systems. Certain processes, recovering certain elements and fixing certain process inefficiencies are picked out of this multitude. This can be shown as unity:

$$\Phi = \bigcup_{i=1}^{c} \varphi_i. \quad (16)$$

Formula (15) can be written this way considering (16):

$$\left(\bigcup_{i=1}^{c} \varphi_i\right) : \left(\bigcup_{i=1}^{n}(\delta a_i)\right) \to \left(\bigcup_{i=1}^{n}(\delta^* a_i)\right). \quad (17)$$

The process of system element recovery is a total of management impact and operations, determined to recover the initial level of system safety and its elements quality, lost while system work. As a result, the system returns to its initial state. Consequently, formula (16) may be reconstructed the following way:

$$\Phi = \varphi_1 * \varphi_2 * \varphi_3 * \ldots * \varphi_i * \varphi_{c-1} * \varphi_c. \quad (18)$$

The management decisions and their structure are described in formula [16] (total of measures, determined to system change, presented as documents), and it is shown in (18), how these decisions influence the real problems, for instance, AEL, in real recovery process [16]:

$$\left| \begin{array}{l} (\varphi_1 * \varphi_2 * \varphi_3 * \ldots * \varphi_i * \varphi_{c-1} * \varphi_c) : (\delta a_1) \to (\delta^* a_1), \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ (\varphi_1 * \varphi_2 * \varphi_3 * \ldots * \varphi_i * \varphi_{c-1} * \varphi_c) : (\delta a_i) \to (\delta^* a_i), \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ (\varphi_1 * \varphi_2 * \varphi_3 * \ldots * \varphi_i * \varphi_{c-1} * \varphi_c) : (\delta a_n) \to (\delta^* a_n). \end{array} \right. \quad (19)$$

System (19) does not suppose the full system quality recovery after all recovery measures sequent implementation to every aspect of performance, as the part of such measures cannot eliminate quality which was compromised during the system operation: $\varphi_j : (\delta a_y) \to \emptyset$.

That is why the purpose of process monitoring and lost quality recovery management system is choosing the sequence of certain recovery measures, resulting in the aim shown in (17).

As a result, it is necessary to find an individual product, meeting process safety requirements, for every single δa_i:

$$\left(\varphi_i * \ldots * \varphi_j\right) : (\delta a_i) \to (\delta^* a_i). \quad (20)$$

Φ multitude in formula (16) is a submultitude of Ω multitude, including all scientifically known recovery processes (c):

$$\Omega = \bigcup_{i=1}^{c} \omega_j. \quad (21)$$

Science constantly develops and improves the recovery methods, instruments and technologies. Power (c) in equation (21) is a temporary function, which usually ascends. It is possible, anyway, that some processes can be lost.

Thus:

$$\Omega\,(t) = \bigcup_{i=1}^{c(t)} \omega_j. \quad (22)$$

As previously mentioned, recovery process (16) is included into (22):

$$\Phi \subset \Omega, \quad (23)$$

$$\left(\Phi\ = \bigcup_{i=1}^{c} \varphi_i\right) \subset \left(\Omega\,(t) = \bigcup_{i=1}^{c(t)} \omega_j\right). \quad (24)$$

System state, in which the full recovery (20) is gained, is described by the fact that all singular performance elements, characterizing the system component and connections quality, become equal to the values of these measures in the beginning of system work:

$$(\varphi_i * \dots * \varphi_j) : (\delta a_i) \to \emptyset. \quad (25)$$

Formula (14) may be reconstructed considering (20):

$$(\varphi_i * \dots * \varphi_j) : (a/\,\delta a_i) \to (a/\,\delta a_i). \quad (26)$$

At the same time:

$$\delta^* a_i \ll \delta a_i, \quad (27)$$
$$\delta^* a_i \le \delta a_i max. \quad (28)$$

Here, $(\delta a_i max)$ is an element of multitude (29):

$$\delta a_i\, max \subset \bigcup_{i=1}^{n} \delta a_i\, max. \quad (29)$$

Results of the research

Process safety management systems must provide conclusive correspondence between both right and left part of the equation (28) according to applicable legislation. Nowadays there is a multitude of probable recovery variants (29), which allows us to use its different methods, which all meet conditions (27) and (28).

$$\left| \begin{array}{l} (\varphi_i * \dots * \varphi_j)1 :\ (\delta a_i) \to (\delta^* a_i)1, \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ (\varphi_i * \dots * \varphi_j)d :\ (\delta a_i) \to (\delta^* a_i)\mathrm{d}, \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ (\varphi_i * \dots * \varphi_j)y :\ (\delta a_i) \to (\delta^* a_i)y. \end{array} \right. \quad (30)$$

According to equation (30), the optimal recovery method can be chosen based on certain criteria (parameters *d*, *y* in equation (30)) or Pareto principle [17].

There is an iconographic model of process safety in Figure 1.

Conclusion

The new approach for modelling process safety management system on airline was carried out in this research and shown in Figure 1.

Mathematical modelling allows us to understand the nature of some phenomena more deeply and reveal the information reflecting the genuine situation and stimulating the development of new scientific challenges and approaches for meeting them, being the basis for certain decisions while running certain projects.

The main management aim is to provide the desirable system finite state. It is possible to

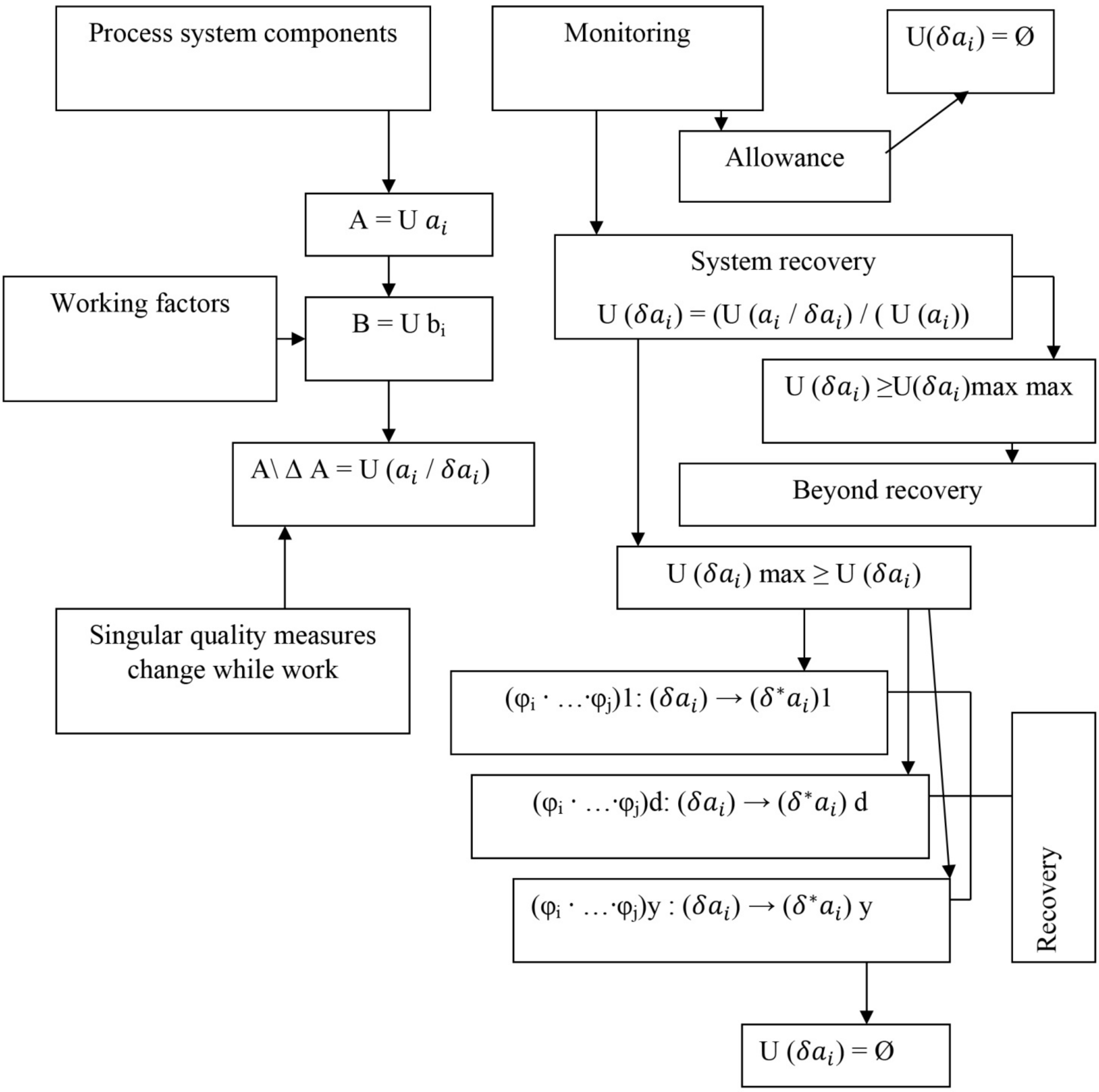

Fig. 1. Iconographic model of process safety

manage different process system components of *A* multitude by means of the developed mathematical model, namely with resources (material, financial, human), processes, work places. The given managing impacts allow us to provide the process safety acceptable level.

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