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DEVELOPMENT OF THE CONCEPT OF AN INTELLIGENT SYSTEM FOR ASSESSING THE OCCUPATIONAL RISK OF AIR TRAFFIC CONTROLLERS

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Abstract. This article examines the occupational risks faced by air traffic controllers, specifically focusing on how their psycho-emotional state and fatigue affect work efficiency and air traffic safety. The study highlights the necessity of monitoring the mental health of controllers as a central factor in minimizing errors and ensuring the consistent operation of aviation services. A concept for an intelligent system to assess occupational risk is proposed, which entails analyzing the fatigue and mental health levels of controllers through hybrid models and expert methodologies. Developing such a system will enable the prompt identification of potentially hazardous conditions and the optimization of work shifts, thereby alleviating stress and fatigue among controllers. The findings of this work can be utilized to enhance training programs, improve workload management for air traffic controllers, and elevate aviation safety standards in future research.

Keywords: air traffic controllers, fatigue level, risks, flight safety, mental health, decision support, fuzzy modeling.

1. INTRODUCTION

Air traffic controllers play an important role in ensuring air traffic safety and making responsible decisions in the performance of their duties. At the same time, their activities are associated with high psychophysiological loads and significant stress, which can lead to various risks, both for the controllers themselves and for the safety of the aviation system. One of the key factors affecting the professional activities of air traffic controllers is their mental health. The psychological state of a controller can directly affect their ability to respond quickly and effectively to changes in working conditions.

In conditions of constant increase in air traffic intensity and complexity of working conditions, air traffic controllers often work in stressful situations, which require a high level of psychophysiological stability and the ability to respond quickly to unpredictable changes. However, long-term work in such conditions can lead to reduced productivity, increased fatigue, and the development of psycho-emotional disorders, which directly affect the safety of the aviation process.

The level of fatigue and mental health are key aspects that directly affect the effectiveness of air traffic controllers' duties. Chronic fatigue, stress, depression, or other psycho-emotional disorders can significantly impair the controller's ability to make informed and quick decisions under conditions of intense workload. Fatigue reduces concentration, reaction speed, and decision-making accuracy, which increases the risk of errors and even emergencies. Mental health disorders, in particular anxiety disorders or depression, can lead to a decrease in resistance to stressful situations and a decrease in overall performance. Therefore, studying these aspects in the context of professional risk is extremely important for creating effective mechanisms for monitoring and supporting the psychological health of air traffic controllers, which will reduce the likelihood of critical situations associated with the human factor.

Thus, it is relevant to conduct a preliminary analysis and develop the concept of an intelligent system for assessing the professional risk of air traffic controllers based on the analysis of their mental health level. This approach will provide a more accurate and individualized risk assessment, reducing the likelihood of errors caused by the psycho-emotional state of employees and increasing the overall efficiency of air traffic safety management.

Over the past decade, there has been a significant increase in scientific interest in the problem of assessing occupational risk in conditions of intense psychophysiological stress, particularly in the aviation industry. Studies indicate a close relationship between the mental health of air traffic controllers and the level of occupational risk, which affects flight safety [1, 2]. Publications [3, 4] highlight the importance of implementing intelligent technologies for analyzing stress, fatigue, and cognitive overload in workers in critical professions. Another paper [5] discusses the current state and challenges of implementing intelligent systems for monitoring and improving mental well-being in the workplace.

Researchers pay special attention to the development of risk prediction models based on neural networks [6], fuzzy logic [7], fuzzy cluster analysis methods, and machine learning [8]. In particular, the effectiveness of such systems is confirmed in works that analyze the fatigue of aviation personnel based on physiological and behavioral parameters [9].

Several studies propose conceptual approaches to the integration of biometric sensors, mobile applications, and cloud platforms for continuous monitoring of the psychophysiological state of dispatchers [10, 11]. Despite this, a significant part of the existing models do not consider the individual mental characteristics of employees or are not capable of real-time adaptation, which creates a need to design more flexible intelligent systems.

Thus, the current state of scientific research highlights the importance of developing an intelligent system capable of assessing the professional risk of air traffic controllers, considering mental health indicators, to enhance the safety of aviation activities and decrease the likelihood of critical errors.

The development of an intelligent system that allows for monitoring and analyzing the mental health and fatigue levels of controllers is a crucial step toward minimizing the risks associated with the human factor. Such a system enables the prompt detection of signs of overload or psychological issues in employees, facilitating timely action to correct their condition, provide necessary support, and prevent potential errors that could lead to serious consequences. This, in turn, enhances air traffic safety, improves working conditions for air traffic controllers, and optimizes the use of human resources in the aviation sector. Therefore, the practical application of this study's results can significantly reduce professional risks and ensure a more stable and safe operation of aviation services.

The aim of the article is to conduct preliminary research to develop the concept of an intelligent system for assessing the professional risk of air traffic controllers depending on the level of mental health.

2. MATERIALS AND METHODS

Let the set of air traffic controllers be denoted A, working at a certain airport. The task is to assess the occupational risk of their activities depending on their level of mental health. The assessment of air traffic controllers will be carried out based on an information model to determine the level of fatigue of air traffic controllers – M_1, as well as using an expert method to assess the level of mental health of air traffic controllers – M_2. As a result, the following indicators will be obtained: $assessment(A)$ – overall predicted quantitative assessment of air traffic controller fatigue; $expert(A)$ – expert opinion on the mental health of air traffic controllers A. The data obtained will be processed using a hybrid model to assess the risk of air traffic controllers' professional activities depending on their level of mental health, M_3.

Formally, an intelligent system for assessing the occupational risk of air traffic controllers can be represented as an operator:

$$M(A, assessment(A), expert(A), M_1, M_2, M_3)|Y(f). \tag{1}$$

Based on input data $A, assessment(A), expert(A)$ and methods of their processing M_1, M_2, M_3 operator M outputs the initial knowledge $Y(f)$, containing the content of the risk of professional activity of air traffic controllers.

An illustration of the processes of operation of the intelligent system for assessing the professional risk of air traffic controllers is shown in Fig. 1.

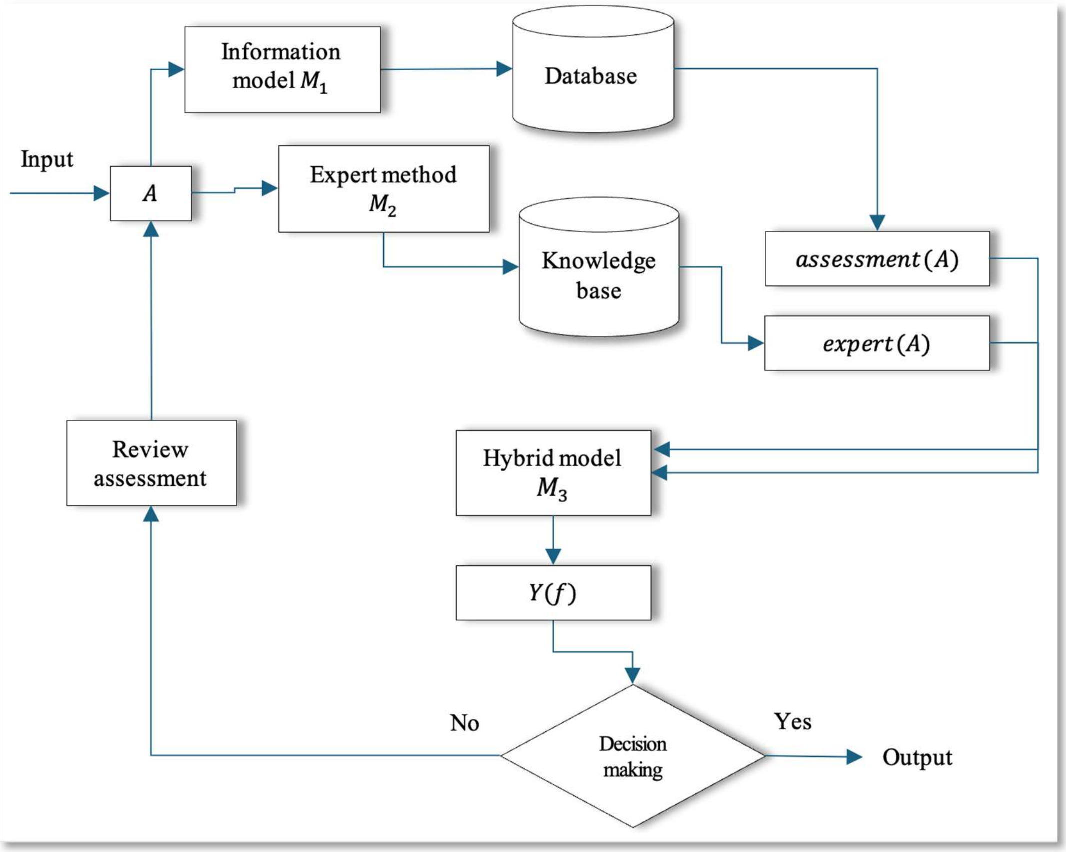

Figure 1 Structural diagram of an intelligent system

The results of the risk assessment of the professional activities of air traffic controllers, based on the analysis of their mental health, are of crucial importance for increasing the level of flight safety. After all, the assessment of the psycho-emotional state of controllers allows for the timely detection of potentially dangerous conditions that can lead to a decrease in the efficiency of their work and, as a result, to the occurrence of errors or incidents. This, in turn, creates the opportunity to develop several effective measures for the timely reduction of the level of fatigue and stress among controllers, as well as for the correction of their psycho-emotional state.

This allows for the development of individualized work schedules for air traffic controllers that consider their psychological state, which will optimize workload and reduce the risk of professional burnout and other stress-related illnesses. Reducing the impact of fatigue and stress not only improves the efficiency of controllers but also reduces the likelihood of errors that can threaten air traffic safety.

In addition, the results of this study can be used to improve educational and training programs for air traffic controllers. Specialist training can be focused on the development of not only professional skills but also psycho-emotional stability, which is a necessary component for successful work in conditions of high loads. The introduction of adaptive methods of load management will allow to flexibly respond to changes in air traffic conditions and ensure the most effective organization of the work of controllers, reducing potential risks to flight safety.

To develop an intelligent system, it is proposed to develop the following models.

Information model for determining the level of fatigue of air traffic controllers – M_1.

The information model should provide a comprehensive assessment of the level of fatigue of air traffic controllers. To do this, specialized hardware and software are used for data collection and processing. A software solution has already been created to monitor the level of fatigue of controllers, which uses algorithms for the dynamic measurement of physiological indicators of fatigue [9]. This software solution can be adapted for use in the information model of this study, including its algorithmic support.

However, it is also possible to use other well-known methods developed by other researchers, which provide a normalized assessment of the level of fatigue at the output.

The developed software solution involves providing input data on a set of air traffic controllers whose fatigue level is assessed in real-time. Initial fatigue data is collected using special technical devices that allow measuring physiological indicators using video surveillance systems. These systems analyze the eye movements of controllers, recording video for a certain time. After that, the video material is transferred to the software module for further processing and analysis to determine the level of fatigue based on partial or complete eye closure. Using a special formula, the program generates a normalized fatigue score, which allows for assessing the physical condition of controllers during their work.

As a result of this process, a general predicted quantitative assessment of air traffic controllers' fatigue is obtained, denoted as assessment(A). The information model makes it possible to continuously monitor the level of controller fatigue, thus ensuring timely detection of critical levels of fatigue. This allows for effective management of work shifts, optimization of the load on controllers, and reduction of the probability of errors, which, in turn, contributes to increased flight safety. The use of such modern technologies allows for significant improvement in the process of managing aviation operations and minimizing human errors, which are critical for air traffic safety.

Expert method for assessing the level of mental health of air traffic controllers – M_2

To develop an expert method, it is necessary to develop a system for assessing the mental health of air traffic controllers. To do this, it is necessary to build an open set of criteria that allow for a comprehensive analysis of various aspects of the psycho-emotional state of air traffic controllers. Within the framework of this approach, the air traffic controller undergoes a specialized survey, in which answers to questions are given in the form of point scores that reflect the level of mental health according to the specified assessment criteria K. The assessment can be carried out on a ten-point scale, where the value 1 indicates "minimum overload", and the value 10 - "maximum overload".

Based on the theoretical-multiple generalization, it is necessary to develop criteria for assessing the mental state of an air traffic controller, which provide a multidimensional and accurate assessment of his psycho-emotional state. These criteria should allow not only the identification of the general level of stress and fatigue but also to consider other aspects, such as cognitive load, emotional overstrain, ability to concentrate, and other important components of mental health, which are critical for the effective work of an air traffic controller.

When developing criteria for assessing the mental state of an air traffic controller based on set-theoretic generalization, it is important to consider several limitations. First, the scores obtained during surveys may be subjective and may not always accurately reflect the real mental state of the controller. In addition, the assessment criteria may not cover all aspects of the psycho-emotional state, such as cognitive load or emotional overstrain, which complicates an accurate assessment. External factors, such as weather conditions or air traffic intensity, which change in real-time, can also have a significant impact on the assessment. Technical limitations, in the use of video cameras for eye movement analysis, can lead to errors in determining the level of fatigue. Additionally, individual differences between controllers, such as physiological or psychological characteristics, make it difficult to create universal criteria. The assessment of mental state may also change during the work shift, which requires constant monitoring. A final limitation is the ethical issues surrounding data privacy and use, which requires ensuring transparency and fairness in the application of these criteria.

After collecting the scores, it is necessary to fuzzify the data, which will allow for the classification of the level of mental health of air traffic controllers into different categories and for determining appropriate recommendations for further actions. For this, the following fuzzification methods can be used:

Fuzzy classification method – this approach allows the use of fuzzy sets to assess different levels of mental health [7]. Using fuzzy logic operators, it is possible to determine the degree to which each result belongs to different categories (e.g., “normal state,” “pre-stress state,” “stressful situation”), even if the estimates have some uncertainty.

Cluster analysis classification – this method allows the group of air traffic controllers based on the similarity of their scores [12]. Using clustering algorithms such as K-means or hierarchical classification, it is possible to identify groups of controllers with similar levels of mental health, which allows the creation of individual recommendations for each group.

Decision tree method – this method can be used to build a model that predicts the level of mental health of a dispatcher based on his or her score [13]. Each node in the tree will represent a critical assessment criterion, and the final leaves will represent specific categories of health status, for example, "normal," "high stress," or "critical condition."

Statistical classification method – based on the obtained data, statistical classification methods such as logistic regression or naive Bayesian classifier can be applied [14]. These methods allow, based on the given criteria, to estimate the probability of an air traffic controller belonging to one of the mental health categories, which will provide a more accurate assessment of the state of controllers.

Neural network method – the use of neural networks allows us to consider the complex relationships between various factors that affect the mental health of air traffic controllers [8]. Thanks to deep learning, neural networks can detect non-obvious patterns in large data sets, which allows us to achieve high accuracy in classifying the state of controllers.

The choice of a specific fuzzification method depends on the nature of the data obtained, the number of assessment criteria, and the requirements for the accuracy of the results. A combination of several methods can also be useful to obtain a more reliable and comprehensive assessment of the mental health of air traffic controllers.

After fuzzification of the data, the formulation of *expert(A)* is carried out - an expert opinion that reflects the general state of mental health of dispatcher A. This opinion is the result of a comprehensive analysis of the obtained assessments and allows us to assess not only the general level of stress and fatigue but also other aspects of the psycho-emotional state. To increase the accuracy of the opinion, additional methods can be used, such as statistical analysis or fuzzy logic modeling, which allow to consider even non-obvious factors affecting the health of dispatchers.

A hybrid model for assessing the risk of professional activity of air traffic controllers depending on their level of mental health – M_3.

The hybrid model involves the integration of several approaches that allow for obtaining both quantitative and linguistic levels of risk. For this purpose, it is proposed to use fuzzy logic inference based on the membership function, which combines data on the level of fatigue of air traffic controllers with expert assessments of their mental health. This allows considering not only objective indicators of fatigue but also subjective assessments of the psycho-emotional state, which provides a more accurate and comprehensive assessment of risk.

To implement such a model, it is first necessary to develop a fatigue assessment system based on video analysis methods and measurement of physiological indicators. Using this approach, a quantitative assessment of the level of fatigue can be obtained (assessment A), which can then be used to further derive the risk of professional activity. At the same time, based on expert opinions on the mental health of air traffic controllers (expert A), it is possible to determine individual characteristics of the psycho-emotional state that also affect the risk. The next stage involves the use of fuzzy logic to derive a quantitative risk assessment. Depending on the level of fatigue and mental health, it is proposed to apply different membership functions that allow calculating the risk value in the range from 0 to 1 for each air traffic controller. Each membership function has different parameters that reflect different levels of fatigue and emotional stability, which, in turn, help to more accurately assess professional risk.

Based on the obtained quantitative risk values, it is also necessary to derive a linguistic risk level, which can be determined on a five-point scale (for example, from R1 to R5). To do this, quantitative risk assessments are compared with defined threshold values, which allow risk to be classified into low, moderate, medium, high, or critical levels. This linguistic risk level helps to better understand not only the quantitative indicators but also allows for making appropriate decisions based on the mental state of air traffic controllers.

To improve this model, additional factors can be considered, such as the duration of the air traffic controller's work, the specific tasks he performs, and external working conditions. This will allow the model to be more flexible and adaptable to real aviation conditions, which will contribute to reducing the risks associated with fatigue and stress, as well as increasing flight safety.

Thus, the intelligent system for assessing the professional risk of air traffic controllers allows them to effectively predict and minimize the risks associated with fatigue and stress, improving the safety of aviation operations. Thanks to personalized approaches and adaptive load management methods, the system optimizes work schedules, reducing the likelihood of errors and increasing the efficiency of controllers.

3. CONCLUSIONS

Thus, an intelligent system for assessing the occupational risk of air traffic controllers based on their mental health is a powerful tool for ensuring safety in the aviation industry. Integrating data on controller fatigue collected through specialized information models and expert assessments of their psycho-emotional state makes it possible to effectively predict and minimize risks that may arise due to the human factor. Appropriate intelligent models allow for the prompt detection of signs of fatigue and stress that may affect the ability of controllers to perform their duties at a high level.

The development and application of such systems allow the timely detection of critical conditions and adaptation of work schedules based on the data obtained, optimizing controllers' workload and reducing the likelihood of professional burnout. The intelligent system also provides the opportunity for a personalized approach to each controller, considering the individual characteristics of their psycho-emotional state. This opens new horizons for improving the quality of work of air traffic controllers and reducing errors that can have critical consequences for air traffic safety.

Another important aspect is the implementation of adaptive workload management methods that allow for instant response to changes in working conditions, which makes it possible to effectively regulate the level of stress and fatigue among controllers, increasing their efficiency and reducing risks to aviation safety.

Further research into this issue involves developing an intelligent system for assessing the occupational risk of air traffic controllers and its detailed verification and testing in actual aviation conditions. A critical stage will be creating software that should ensure the integration of all model components, including monitoring the level of fatigue, assessing mental health, and determining the level of occupational risk. It is also necessary to conduct a comprehensive check of the accuracy, reliability, and effectiveness of this system based on data received from air traffic controllers in real time to ensure its practical application and adaptation to various conditions.

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