Forecasting and Managing Professional Risks Using Information-Analytical Systems Based on Fuzzy Logic Methods

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Abstract. The article presents the results of studies aimed at improving the effectiveness of professional risk management in enterprises of various industries. For this purpose, an information-analytical system has been developed. It consist of modules for accumulating and processing statistical information about incidents, qualifications, competence of employees, a module for forecasting incidents and determining the degree of risk, and a module for determining options for management decisions. The proposed modules are components of a comprehensive integrated occupational safety management system. It has been designed to determine the level of professional risk of personnel of industrial enterprises and hazardous production facilities and ensure the safety of production activities. Using the product will allow enterprises to interactively monitor the dynamics of personnel competency indicators, the technical condition of production facilities, external factors and predict the risks of accidents and emergencies at enterprises and hazardous production facilities. The use of a fuzzy analysis of incidents by various factors makes it possible to compare data on the personnel of enterprises and evaluate the statistical probability of incidents and accidents. This allows us to identify categories of employees of enterprises for whom the value of occupational risk exceeds the allowable values, and make decisions to reduce it.

1. Introduction
Despite intensive automation and robotization of the industry and increasing energy flows in the production of substances and materials, the role of man in production processes remains central. At the same time, in case of non-observance of occupational safety requirements, both by workers and employers, the number of emergencies, industrial accidents increases, the level of occupational injuries remains high [1, 2]. According to experts, the annual non-reimbursable cumulative material damage from natural and man-made emergencies and industrial injuries may annually amount to 10 – 15% of gross domestic income [3, 4]. Therefore, it is necessary to organize work to prevent emergencies and industrial accidents, improve occupational safety and predict the psychophysical and psycho-emotional state of workers. The development of an information-analytical system for forecasting and managing professional risks in unsafe production is of particular relevance [5, 6].
The main reason (80 – 90%) for the occurrence of industrial accidents is the human factor, namely the possibility of a person making erroneous or illogical decisions in specific situations. Errors, called the manifestation of the human factor, are usually unintentional: a person performs erroneous actions, regarding them as true or most appropriate [7–10].

The reasons for this human behavior may be the lack of information support. This problem is especially evident in extreme situations and in conditions of a lack of time for decision making.

The implementation of occupational risk management systems will significantly reduce the level of occupational injuries of workers and accidents at enterprises and hazardous production facilities. Currently, such complex automated systems, as well as models, methods, and algorithms for determining occupational risk levels and predicting unsafe employee behavior, have not been sufficiently developed, which confirms the relevance of research [11–14].

Among the facilities with hazardous production, for which the problem of introducing innovative occupational safety management systems is of great importance, there are mining enterprises, the construction industry, agriculture, housing and communal services and transport, manufacturing. The product can be adapted for use in an enterprise of any profile. The target groups are enterprises with high rates of industrial injuries and accidents.

2. Results and discussion

Currently, expert systems have been developed to assess the probability of industrial accidents during the operation of technological facilities and man-machine systems (including hazardous production facilities), as well as the reliability and safety parameters of complex technical systems.

Abroad, work is underway to create models of unsafe behaviour for employees based on an analysis of indicators of their behaviour and the working environment, such as the level of management control, working conditions, safety management system, level of employee participation, level of knowledge of safety requirements, attitude to safety, motivation, resource allocation and work stress [13–14]. Analysis of the work of M. Amiri, A. Ardeshir, M.H. F. Zarandi (2017), M. Abdelgawad, A. Robinson Fayek (2001) showed that they are based on predictive modelling of incidents based on known statistics for certain types of jobs and professions, however, foreign studies do not take into account constantly changing factors of the production environment, the labour process, and changes in the psychoemotional and physiological state of the employee.

The basis of the developed information-analytical system for managing professional risks [21], part of which is a system for predicting the behaviour of an employee in an enterprise with dangerous working conditions, is the client-server architecture. It allows you to organize control over the condition of workers, the workplace and other factors using various tools (including sensory systems), as well as organize workplaces for assessing the competence of personnel in the field of labor safety (in the form of testing), its psychophysiological and psychoemotional condition. The general architecture of the system is shown in Figure 1.

The information-analytical system of professional risk management consists of the following subsystems:

- Base of source statistics on industrial injuries:
  - data on the personnel of the enterprise;
  - job parameters;
- Information and analytical system for monitoring emergency situations at an enterprise with dangerous working conditions:
  - personnel competency assessment module;
  - a module for assessing factors of working conditions and the labor process in real time;
  - module for assessing the physiological state of an employee;
- A system for predicting employee behavior in an enterprise with hazardous working conditions:
  - data processing module;
  - employee risk assessment module;
• professional risk management module – issuing recommendations for making managerial decisions.

![Figure 1](image-url) General architecture of the information-analytical system of professional risk management.

The principle of the system is as follows. At the first stage of work with the system, an information database is filled in on the personnel and workplaces of the enterprise.

Then, based on a well-known database of statistical indicators and the dynamics of injuries in the industry, a preliminary risk assessment of the incident (unsafe employee behavior) is given, taking into account the known dependencies of the frequency of accidents on a number of factors: gender, age, shift time, marital status, education, etc.

Based on the assessment made and the forecast of the occurrence of a potentially dangerous action, the system makes a recommendation for its elimination or reduction.

The main functions of the product at the exit:
- the formation of databases of indicators characterizing the qualifications and competence of the employee in the field of occupational safety in real time;
- assessment of individual occupational risk;
- determination of correlation between such indicators as: qualification, level of competence in the field of labor safety, and the risks of accidents;
- analysis and forecasting of probable incidents and / or changes in the employee’s condition to reduce occupational injuries.
- identification of groups of workers for which occupational risk indicators exceed the permissible value (risk groups).
- the formation of recommended options for action (control decisions) for decision makers (DM) to prevent a possible incident.

In the process of designing the system, it was decided to use a functional approach. IDEF0 methodology allows you to describe all business processes present in the system with an accuracy sufficient for modeling.

In Figure 2 the context diagram IDEF0 is presented, which reflects a general description of the activity of the employee behavior forecasting system.
Figure 2. Context diagram IDEF0, the functioning of the system for predicting the behavior of an employee in an enterprise with dangerous working conditions.

The input data are the statistical indicators of the employee from the database of accidents at enterprises and hazardous production facilities of the Belgorod region, which contain the causes of work-related injuries collected for 2007 – 2018. Also the input data are the results of the emergency monitoring system in the form of data from the testing module, employee sensor readings and workstation sensor readings. The functional of the system is supported by software, which is divided into general (operating system, drivers, etc.) and specialized (developing information system, etc.). Based on the organization’s policy and the level of professional risk, the official responsible for ensuring safety in the field of labor protection accepts a manager decision on admission or non-admission of an employee to the workplace.

The work of the expert system is based on an analysis of factors affecting the probability of production incidents, determining the probability of its occurrence and then comparing the model risk value (probability of an event) with a scale of probable damage (severity of an event). Elimination of inaccuracies in risk assessment to a greater extent can be solved by introducing formal logic methods and methods based on the theory of pattern recognition, developments in the creation of artificial intelligence, the theory of fuzzy sets, fuzzy logic [15–20]. The method of fuzzy inference of the consequences of an accident can be represented in the form of several successive steps [21, 22].

Stage 1. Formation of accessory functions.

During the observation of n objects (workers) for some time, it is established that for some interval \(i (i = \Gamma_{\tau})\) of the parameter \(j (j = \Gamma_{\tau})\) the severity of “Class 1” is recorded \(k\) times (the following set of weights takes place: “Class 1”, “Class 2”). According to the results of observation, the expert fixes the frequency of hitting a certain interval of the parameter in the risk value:

\[
p_i = \frac{k_i}{n}.
\]

Stage 2. Fuzzy composition.

The stage of a fuzzy composition consists of two operations:
– the operation of determining the degree of belonging of a point;
– logical conjunction operations.

The first operation is used to determine the degree of belonging of the point characterizing the state of the worker to a certain area of severity (\(\mu_{\text{min}}\)).

The second operation, namely, the operation of logical conjunction, is used to determine the minimum value of the assessment of the degree of belonging of the image of the state to the corresponding region of severity, which is carried out by a comparative analysis of the resulting sets of assessments. Then for all values of the selected input variables of the mathematical model of fuzzy inference, we get:

\[
\mu_{\text{min}} = \min \{\mu_{1T}, \mu_{2T}, \mu_{3T}\}.
\]
Stage 3. Development of the production knowledge base model in the form of fuzzy rules.

The fuzzy knowledge base is used to interact between input and output parameters and implement decision support. The fuzzy knowledge base is a finite set of fuzzy rules (FR). With reference to the illustrated classes of consequences severity and based on all the values of the selected input variables of the fuzzy inference mathematical model, the following production rules can be formed:

1. FR 1: If \( \mu_{\text{min}} = \mu_{\text{min}} \), then «Class 1»;
2. FR 2: If \( \mu_{\text{2min}} = \mu_{\text{max}} \), then «Class 2».

3. Conclusion

An information-analytical system has been developed. It consist of modules for accumulating and processing statistical information about incidents, qualifications, competence of employees, a module for forecasting incidents and determining the degree of risk, and a module for determining options for management decisions. The proposed modules are components of a comprehensive integrated occupational safety management system. It has been designed to determine the level of professional risk of personnel of industrial enterprises and hazardous production facilities and ensure the safety of production activities. Using the product will allow enterprises to interactively monitor the dynamics of personnel competency indicators, the technical condition of production facilities, external factors and predict the risks of accidents and emergencies at enterprises and hazardous production facilities. The use of a fuzzy analysis of incidents by various factors makes it possible to compare data on the personnel of enterprises and evaluate the statistical probability of incidents and accidents. This allows us to identify categories of employees of enterprises for whom the value of occupational risk exceeds the allowable values, and make decisions to reduce it.

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