Decision-making process modeling for occupational safety management system based on a fuzzy analysis of production incidents

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Abstract. The article proposes a decision-making model using a fuzzy analysis of production incidents for various factors. For the analysis, a database of factors of industrial incidents that occurred in the Belgorod region in 2007-2017 is used. The model is based on a quantitative assessment of the degree of belonging of the current value of the state parameters to each of the scenarios of severity of consequences at the corresponding point. This model is implemented in an expert decision support system for occupational safety and risk management. The use of such systems allows one to provide multivariate analysis of occupational injuries and occupational risk factors and to identify groups of workers for whom the level of occupational risk exceeds acceptable values.

Keywords: professional risk, expert information decision support system, injuries, occupational health and safety system, interactive prediction of incidents, fuzzy sets, fuzzy logic

1. Introduction

Ensuring safe working conditions and prevention of industrial incidents and accidents are important conditions for increasing labor productivity and efficiency of industrial production [1, 2]. Despite all efforts, the low level of safety culture of labor, and as a result, the high level of industrial injuries in the Russian Federation is still one of the factors that influences the economic development of the country. According to the data of the Ministry of Labor and Social Protection of the Russian Federation, only in 2017 in the country the number of people injured in industrial accidents was 25445; the number of fatalities was 1138 [3].

As practice shows, the main cause (80 – 90%) of all accidents at work is the human factor [4]. The human factor is the ability of a person to make erroneous or illogical decisions in specific situations, as well as errors caused by changes in the psychological and / or physiological state of a person due to the influence of factors of the working environment and labor process, the lack or insufficiency of information support. This problem is especially pronounced in extreme situations and in conditions of lack of time for decision making.

The task of reducing the level of occupational accidents and labor safety management (occupational risk management) should be solved taking into account the dynamics of changes in all factors affecting it (working conditions and employee actions). The use of a cyber-physical approach (cyber-physical
systems as part of an integrated information and analytical system of enterprise management) can be an effective tool for the dynamic management of occupational safety [5–8].

The main element of the dynamic occupational safety management system is an expert decision support system. An expert decision support system is a computer information system that is designed to solve assigned tasks by simulating the knowledge and reasoning of experts [9–11]. In order to effectively manage occupational risks, this paper proposes an expert decision support system of a dynamic type, which allows analyzing a large number of factors causing industrial injuries in real time. The use of such systems allows for multivariate analysis of occupational injuries and occupational risk factors and to identify groups and categories of workers for whom the level of occupational risk exceeds acceptable values.

This paper presents the results of modeling the decision-making process in the expert system using the fuzzy analysis method of industrial incidents.

2. Methodology
One of the options for overcoming uncertainties is the use of fuzzy concepts and knowledge, operating on them with the use of fuzzy logic rules and obtaining fuzzy conclusions based on them, on the basis of which the law of logical control is formed. In these cases, the mathematical theory of fuzzy sets, which was proposed by L. Zadeh (USA), is used, and the logic, which is built on the basis of this theory, is called fuzzy logic. Controls that are based on fuzzy logic are commonly referred to as fuzzy logic control [12, 13].

In practice, decision-making on the basis of fuzzy sets requires the presence of membership functions, with the help of which linguistic information is transformed into a convenient form for processing on a computer.

The following basic methods exist for constructing membership functions of fuzzy sets [14, 15]:

- method, based on a pair-wise comparison matrix (Saaty method);
- using statistical data;
- building membership functions based on expert assessments;
- parametric method;
- construction of membership functions based on interval estimates.

3. Results and discussion
The work of the expert decision support 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).

The expert decision support system has the following elements:

- input data \( x_i, i=1,\ldots,m_1 \) – factors which determine the state of the external environment and internal characteristics of the control object;
- output data \( y_j, j=1,\ldots,m_2 \) – quantitative indicators of the state of the control object;
- control variables \( u_k, k=1,\ldots,m_3 \) – effects that the control subject can carry out in order to change the characteristics of the control object.

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.

The analysis of accidents at hazardous production facilities can be represented in the form of several successive steps. The first stage includes the collection and preprocessing of data that contain the causes of occupational injuries collected from industrial enterprises of the Belgorod region of the Russian Federation for 2007 – 2017 (materials of investigations of real accidents that occurred in the Belgorod region were used) [16]. The second stage is the analysis of the prepared data from the first stage. After completing these steps, it is possible to predict and simulate the occurrence of accidents, which will make it possible to achieve a significant reduction in the level of occupational injuries and accidents at enterprises and hazardous industrial facilities.
The data generated for each accident include 36 parameters, namely, the name, surname of the victim; the severity of the accident; the date and month of the accident; codes of types and causes of the accident; date of birth of the victim. It includes the age and sex of the employee at the time of the accident; date of commencement of employment of the victim; total work experience of the victim in the organization; the work experience of the victim by profession in the performance of which the accident occurred; time of day of the accident; elapsed time from the beginning of the shift; day of the week of the accident; date of induction. It contains the date of the second (last) briefing; elapsed time after the briefing (in days); date of training and examination of labor protection; the time elapsed after the examination of knowledge of labor protection (in days); internship period; availability of personal protective equipment for the affected person; the date of the special assessment of working conditions / certification of workplaces for working conditions. In addition, there is a class of working conditions; the list of hazardous and harmful production factors affecting the employee, according to the results of a special assessment of working conditions; the presence of alcohol / drugs in the blood of the victim at the time of the accident; marital status of the victim; victim education; name of the enterprise where the accident occurred; branch of the enterprise; additional information about the incident.

The method of fuzzy inference of the consequences of an accident can be represented in the form of several successive steps.

**Stage 1. Formation of accessory functions.**

At the first stage, the parameter membership functions are determined and constructed.

As an example of the input variable of a mathematical model of a fuzzy inference, we consider one indicator of an employee – age. An example of the distribution of injured by the factor “age” is shown in Figure 1.

![Figure 1. An example of the distribution of injured by the factor “age”](image)

As a method for constructing membership functions, a method using statistical data was chosen. It provides for a list of parameters with their quantitative indicators of the frequency of meetings for specific events. The scale of parameters is divided into fixed intervals (for example, the scale of the parameter age is divided into intervals of 0 – 25, ..., 35 – 40, 40 – 45, ..., 60 – 85).

During the observation of \( n \) objects (workers) for some time, it is established that for some interval \( i \) of the parameter \( j \) 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:

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

Based on these statistics, a histogram is constructed (Figure 2).

The matrix of assessment evidence has the form, which is presented in Table 1.
Figure 2. The histogram of statistical data on the parameter “age”

Table 1. The number of hits of the parameter in a certain interval (Matrix of evidence assessment – the age of the employee)

| Age | <25  | 25–30 | 30–35 | 35–40 | 40–45 | 45–50 | 50–55 | 55–60 | 60>  |
|-----|------|-------|-------|-------|-------|-------|-------|-------|------|
| Class 1 | 58   | 62    | 84    | 91    | 67    | 100   | 93    | 66    | 20   |
| Class 2 | 18   | 32    | 36    | 46    | 50    | 75    | 93    | 81    | 33   |

The universal scale [0, 1] contains the values of the intervals for each parameter. Then the degree of membership of a certain value is calculated as the ratio of the number of experiments in which it occurred in a certain interval of the scale to the maximum number of experiments for this value over all intervals:

\[ c_{i_{\text{max}}} = \max c_{ij}, i = 1,3, j = 1,10, \quad (2) \]

\[ \mu_i = \frac{c_{ij}}{c_{i_{\text{max}}}}, i = 1,3, j = 1,10, \quad (3) \]

where \( c_{ij} \) – the elements of the evidence assessment matrix.

The values of the membership functions \( \mu_{ij} \) are given in Table 2.

Table 2. The matrix of values of membership functions by the parameter “age”

| Age | <25  | 25–30 | 30–35 | 35–40 | 40–45 | 45–50 | 50–55 | 55–60 | 60>  |
|-----|------|-------|-------|-------|-------|-------|-------|-------|------|
| \( \mu_{1i} \) | 0.58  | 0.62  | 0.84  | 0.91  | 0.67  | 1.00  | 0.93  | 0.66  | 0.2  |
| \( \mu_{2i} \) | 0.19  | 0.34  | 0.39  | 0.49  | 0.54  | 0.81  | 1.00  | 0.8   | 0.35 |

Using the obtained values of \( \mu_{ij} \), we construct the membership functions (Figure 3).

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 (\( \mu_{\text{int}} \)).

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:
After performing the logical conjunction operation for all values of the selected input variables of the mathematical model of fuzzy inference in accordance with (4), we obtain the following set of quantitative estimates $\mu_{\min}$:

$$\mu_{\min} = \min\{\mu_{1T}, \mu_{2T}, \mu_{3T}\};$$

$$\mu_{\min} = \min\{\mu_{1T}, \mu_{2P}, \mu_{3L}\}; \quad \mu_{2\min} = \min\{\mu_{2T}, \mu_{2P}, \mu_{2L}\}. \quad (5)$$

**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 $\mu_{1\min} = \mu_{\min}$, then «Class 1»; (6)
2. FR 2: If $\mu_{2\min} = \mu_{\max}$, then «Class 2». (7)

Analyzing the dependence of the severity of accidents on the indicator – “worker's age” using the theory of fuzzy sets (according to formulas (1) ÷ (7)), it is possible to quantify the degree to which the current value of each state parameter belongs to each of the consequences severities at the corresponding point.

The given production rules are not only formed on the basis of the selected input variables of the mathematical model of a fuzzy inference, but can be extended depending on the presence of a larger number of input variables.

**Conclusion**

In the process of analysis, we identified certain subjectivity in the choice of membership functions and the formation of fuzzy input rules. However, the obtained scientific and practical results allowed us to draw conclusions that the theory of fuzzy sets allows using fuzzy data of industrial accidents; include qualitative variables in the analysis; to carry out a quantitative assessment of the degree of belonging of the current value of the state parameters to each of the scenarios of severity of consequences at the corresponding point; quickly simulate complex dynamic systems; compare them with a given degree of accuracy; use the explanatory component and, as a result, obtain reliable and accurate results.

The proposed decision-making model is implemented in an expert decision-making system in the field of occupational safety management for industrial enterprises of the Belgorod Region. 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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