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Expert Information-Analytical Decision Support System for Professional Risk Management Based on the Database of Real Cases of Industrial Injuries

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Abstract. The article shows that professional risk is caused by many interrelated factors, which is a big problem when developing ways to manage it. It is shown that one of the most effective professional risk management tools is the use of expert decision support systems using the methods of predictive modelling of events and incidents. The effective operation of such systems should be based on databases of occupational risk factors, created on the basis of a study of the causes of real cases of industrial injuries. In the work, analysis and statistical processing of data on 593 accidents for the period of time from 2012 to 2016 that occurred at the enterprises of the Belgorod region was carried out. Using univariate analysis of variance, the most significant factors affecting the level of industrial injuries were identified. A database on occupational injury factors was created, which became the basis for an expert decision support system in the field of occupational safety management.

1. Introduction

In accordance with the Labor Code of the Russian Federation, professional risk is the probability of causing harm to health as a result of exposure to harmful and (or) dangerous production factors when the employee performs duties under an employment contract or in other cases established by the Labor Code of the Russian Federation and other federal laws [1]. Risk management is the collection and analysis of information on industrial safety, risk analysis (hazard analysis) and safety monitoring [2, 3]. Accordingly, one of the methods in allowing a professional to reduce the risk is to collect statistical information about the problem situations in the workplace and conduct the initial analysis.

Numerous researches of Russian and foreign scientists show that the level of professional risk depends on the set of probabilistic characteristics and the complex of connections between the working conditions, the labor process, the physiological and psychological state of a person, the availability and level of development of institutions for protection against risks (labor protection, social insurance, etc.) [4 – 8]. In addition, it is necessary to take into account that modern production is a complex of technical, social, economic and information systems. Thus, the task of assessing and managing occupational risks and occupational safety is characterized by an unclear initial data and incomplete information for making management decisions in real time. This creates certain difficulties in making such decisions for managers and specialists of enterprises responsible for ensuring occupational safety. Therefore, in order



to reduce occupational risk levels and the probability of injury at accidents, it is necessary to develop methods for assessing and forecasting occupational injuries and occupational hazards based on modern information technologies.

2. Relevance, scientific significance of the issue

According to the data of the Ministry of Labor and Social Protection of the Russian Federation, the number of people injured in accidents at work is about 30,000 people per year; the number of fatalities reaches 1,200 – 1,400 people. This fact makes the management of professional risks and the search for new technologies and methods of their reduction extremely urgent.

Modern tools for predicting incidents and unsafe employee behavior are algorithms created on the basis of various technologies that combine the capabilities of a computer and the Internet. At the same time, intelligent systems based on neural network models, Markov networks, Bayesian networks and other models are used.

The works of Russian scientists are mainly aimed at assessing and managing occupational risks for the health of workers, including bioinformatics technologies [9]. A methodological basis for the management of occupational risks to the human health of an operator is the P.K. Anokhin theory of functional systems. On the basis of intelligent neural systems, cognitive technology has been developed to evaluate the influence of harmful production factors [10, 11].

Overseas, there are attempts to create models of unsafe behavior of workers based on an analysis of indicators of their behavior and working environment, such as the level of management control, working conditions, the safety management system, the level of employee participation, knowledge of safety requirements, safety attitudes, motivation, resource allocation and production stress.

Foreign models of analyzing the behavior of workers are based on the theory of Bayesian networks [12–18]. The following technologies are used in the basis of foreign expert systems:

- Fault Tree Analysis (FTA);
- Failure Mode and Effects Analysis (FMEA);
- Fuzzy Analytic Network Process;
- Bayesian Networks;
- Graphical Evaluation and Review Technique;
- Neural Networks.

All of the above listed methods of analyzing and forecasting incidents, erroneous actions of personnel, accidents and emergency situations make it possible to create integrated software products that are designed to facilitate occupational safety control and management processes in enterprises, hazardous production facilities, etc.

It should be noted that the results of well-known domestic and foreign studies are not fully brought to practical implementation in the form of expert labor safety management systems introduced at real enterprises.

3. Results and discussion

Expert decision support systems are a promising tool for assessing, modelling and managing professional risks. 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 [19, 20]. Given the large number of factors causing industrial injuries, for effective management of occupational risks, it is necessary to develop expert systems for decision support of a dynamic type operating in real time.

The use of such systems allows for multi-factor analysis of industrial injuries and occupational risk factors and to identify groups and categories of workers for whom the level of occupational risk exceeds acceptable values.

The results of a multifactor analysis of occupational risk are used by an automated accounting system for forecasting and managing occupational risks, which allows optimizing the occupational safety management system at an enterprise, studying injury data both for labor safety specialists, and managers and employees at various levels of the enterprise.

At Belgorod State Technological University named after V.G. Shukhov the expert decision support system for the occupational safety management has been developed [19]. The scheme of work the expert decision support system is shown on Figure 1. This system has following elements:

- Input data $x_i, i=1, \dots, m_1$ – factors, which determines the state of the external environment and internal characteristics of the control object;
- Output data $y_j, j=1, \dots, m_2$ – quantitative indicators of the state of the control object;
- Control variables $u_k, k=1, \dots, m_3$ – effects that the control subject can carry out in order to change the characteristics of the control object.

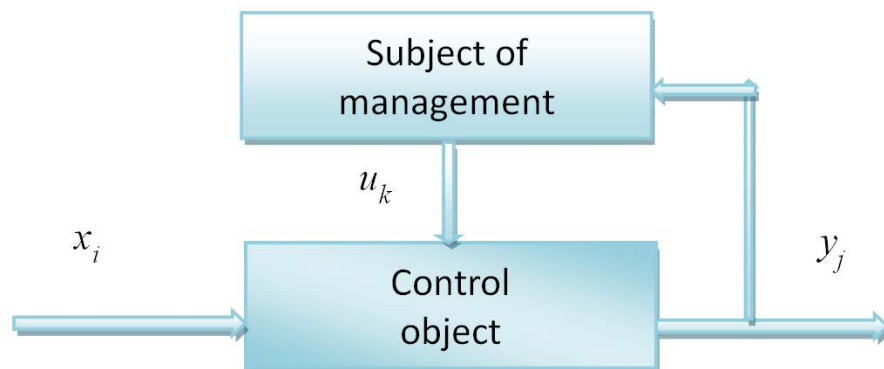


Figure 1. The scheme of work the expert decision support system

The main function of the developed information system is the ability to forecast the level of occupational risk (in terms of industrial injuries) for certain professions, industries and enterprises based on the analysis of events using fuzzy logic and logical-probabilistic modeling. The information system allows to produce:

- retrospective analysis of statistical indicators of injuries by quantitative statistical assessment of factors causing industrial injuries (based on information from investigation materials of real accidents);
- predictive analysis of the magnitude of injuries and occupational risks on the basis of fuzzy logic methods;
- quantification of traumatic factors based on the expert method;
- identification of problematic workplaces;
- selection of a management solution for managing the level of occupational risk (the basis for decision options for managers and specialists of enterprises responsible for ensuring occupational safety).

The first stage in the development of an expert information-analytical system is the creation of a database of current statistical data on the causes of real accidents and factors affecting its probability.

Thus, the main reason for the majority of accidents and occupational injuries was and still is the so-called human factor, which should be understood as a number of factors, such as shortcomings in the vocational training and competence of the employee, the psychological state, the worker's motivation, age, gender, work experience, level of education, time of shift, work schedule, marital status and others. These factors must to be taken into account when monitoring, assessing and predicting occupational risk indicators in the workplace.

Based on the analysis of materials of investigations of real accidents that occurred in the Belgorod region of the Russian Federation from 2012 to 2016, the distributions of the number of injured and dead in accidents at work were obtained. An example of the distribution of injured by the factor "age" is shown on Figure 2. For the analysis, the most traumatic sectors of the economy in the Belgorod region were selected – manufacturing, agriculture, construction and mining.

For purpose of this work 593 accidents for the period from 2012 to 2016 occurred at the enterprises of the Belgorod region were analyzed. Statistical data processing and univariate analysis of variance

using the Statistica software package and Microsoft Excel were performed. The results of the analysis of the factors are presented in table 1.

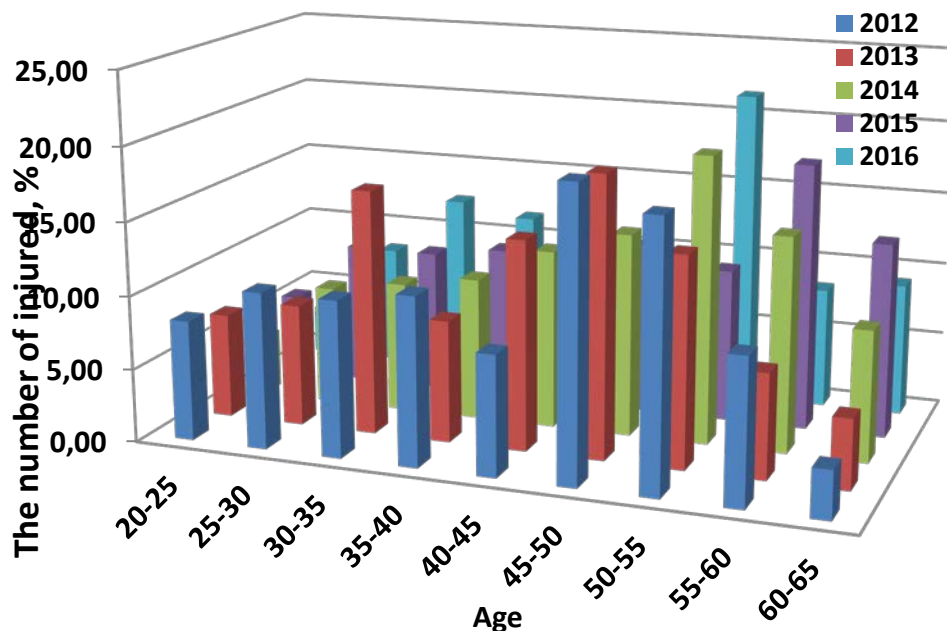


Figure 2. An example of the distribution of injured by the factor "age"

To assess the significance of the results obtained and calculate the probability of injury to workers, taking into account the influence of the factors discussed above, an analysis of the results was carried out using the methods of mathematical statistics.

For this purpose, a univariate analysis of variance was carried out for each factor studied that influences industrial injuries. According to the hypothesis of no differences between groups three estimates of general dispersion proportional to degrees of freedom can be found [20]:

Analysis of variance consists in comparing “factor dispersion” caused by exposure to a factor and “residual dispersion” due to random causes. If the difference between these variances is significant, then the factor has a significant effect on the quantity being studied; in this case, the average of observations on each level (group average) will also vary significantly.

The decomposition of dispersions has the form [22]:

$$D_{gen} = D_{fact} + D_{res} \quad (1)$$

where D_{gen} – the total variance of the observed values (option) characterized by the variation of the variant from the general average; D_{fact} – factorial (intergroup) variance, characterized by difference in averages in each group and depends on the influence of the studied factors by which each group is differentiated; D_{res} – residual (intragroup) dispersion, which characterizes scattering options within groups.

The F-criterion uses the relation between the Student’s distribution and the F-distribution $F_{1,f}=t^2_{f,}$, where $F_{1,f}$ is a random variable having a Fisher distribution with $f_1=1$ and $f_2=f$ degrees of freedom. In the presence of the sample $x_1, \dots, x_n$ and $y_1, \dots, y_n$, the statistics of the criterion for testing the null hypothesis $H_0: \mu_1 = \mu_2$ has the form:

$$F = \frac{(n_1 + n_2 - 1)(n_2 \sum x_i - n_1 \sum y_i)^2}{(n_1 + n_2) [n_1 n_2 (\sum x_i^2 + \sum y_i^2) - n_2 (\sum x_i)^2 - n_1 (\sum y_i)^2]} \quad (2)$$

Table 1. The results of univariate analysis of the factors of industrial injuries according to data on real cases of injuries in the Belgorod region

Name of the factor	Value F	Value F_{crit}
Age	5.294769	2.208518074
Work experience in the organization	145.959	2.445259395
Work experience in the profession	58.75235	2.312741187
Times of Day	15.59006	1.994580015
Time from the beginning of the work shift	6.494849	1.899264953
Day of the week	11.0139885	2.445259395
Month of the year	0.84087	1.994580015
Time after checking the knowledge of labor protection requirements	8.831621	1.899264953
Time after instruction	25.95421	2.312741187
The level of education	4.627113	3.885293835
Family status	167.7901	5.317655072

According to the results of the univariate analysis of variance, we can conclude that only one factor – the month of the year – can be considered to have a minor effect on the level of occupational injuries, since the value of the criterion $F = 0.84 < F_{crit} = 1.99$.

In the second stage in the development of an expert information-analytical system is the functions of the linguistic variables of the severity of the incidents consequences are determined and constructed. As a method for constructing membership functions, a statistical data processing method was chosen. It provides a list of incidents with its quantitative indicators of the frequency of occurrence for specific parameters. According to the number of hits of a certain parameter value within a certain interval, the severity of the incidents consequences determines the values and builds the corresponding membership functions.

For the processing of statistical data, matrices of injury factors were constructed, ranked by the degree of their influence and frequency of occurrence. The elements of the matrices were calculated by the formula (3):

$$k_i = \sum_{j=1}^{m_1} x_{ij} \quad (3)$$

The matrix of factors is a specific row from which the maximum element $k_{max} = \max k_j$ is selected, after which all elements of the matrix are converted by the formula (4):

$$c_{ij} = \frac{x_{ij} k_{max}}{k_j} \quad (4)$$

The membership function is calculated by the formula (5):

$$\mu_{ij} = \frac{c_{ij}}{c_{i max}} \quad (5)$$

A fuzzy composition stage consists of two logical conjunction operations. The first operation is used to determine the degree of belonging of the point, which characterizes the state of the worker, to each severity of consequences. The second operation is used to determine the minimum value of the assessment of the degree of belonging of the parameters to the appropriate severity class of consequences, which is carried out by a comparative analysis of the resulting sets of assessments.

The fuzzy knowledge base (database of real cases of incidents) is used to interact between input and output parameters and implement decision support. Fuzzy knowledge base is a finite set of fuzzy rules. With reference to the illustrated classes of severities and on the basis of all values of the selected input variables of the mathematical model of fuzzy inference, production rules are formed.

The definition of the membership functions and dependencies of the probability of an accident on the industrial injuries factors makes it possible to predict the number of accidents that may occur. Example of matrix of probability – damage severity is given in the Table 2.

Table 2. The occupational risk magnitude quantification (matrix of probability – damage severity)

The damage severity and the weighting factor magnitude	The risk magnitude with probability (frequency) and weighting factor of the damage occurrence		
	Low – 0.3	Average – 0.7	High – 1.0
Low – 0.3	0.1	0.2	0.3
Average – 0.7	0.2	0.5	0.7
Serious – 1.0	0.3	0.7	1.0

Based on the obtained forecast and taking into account the constructed matrices of risk dependencies on the frequency and severity of the consequences of the event, the expert system forms an accurate manage solution (control variables u_k) for incident prevention.

4. Conclusion

An interactive functional expert information and analytical decision-making support system in the field of occupational safety management and occupational risk management has been developed, which will find application in enterprises of any sector of the economy and will be an effective tool to reduce injuries. The analysis of real cases of industrial injuries allowed to create a database of causes of accidents, typical for enterprises of all industries in the region (the Belgorod region of the Russian Federation) and becoming the main module of expert information and analytical decision support system in the field of occupational safety management. The fuzzy knowledge base (database of real cases of incidents) is used to interact between input and output parameters and implement decision support for specialists of industrial enterprises, who are responsible for occupational safety ensuring.

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