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Original Article

Scientific Support of Occupational Risk Management Decisions in Industrial Sectors in Case of Uncertainty

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ABSTRACT

Introduction: The lack of generally accepted techniques (methods, algorithms) that can be used to quantify the risk of injury in the workplace today necessitates appropriate theoretical and experimental studies. Since labor protection management is carried out by planning and implementing preventive measures, a scientific justification for the priority of these measures is required.

Methods: In this study, theoretical methods were used, namely: analysis of modern methods for occupational risk assessing and labor protection managing; synthesis to improve the decision-making algorithm that ensures effective management of labor protection at enterprises; expert evaluation of the weighting coefficients of potential hazards and questioning of employees; mathematical modeling and the modified Elmery method were applied for practical testing of theoretical results.

Results: An occupational risk management algorithm has been developed to substantiate management decisions on planning measures to reduce risk, the implementation of which ensures the effectiveness of measures aimed at reducing risk. If the decision-making situation is characterized by conditions of uncertainty (it is impossible to obtain mathematical models of acceptable accuracy), the assessment of the predictive values of occupational risk is carried out exclusively by an expert. Practical testing of the algorithm shows that the deviation of the values of expert estimates from the results of measurements by an automated control system and portable equipment ranges from 2 to 6%. Therefore, for a quick calculation of risks, it is advisable to use the expert method, as the most economical and fairly accurate.

Conclusion: It has been established that in conditions of uncertainty (lack of necessary data or available data are incomplete or unreliable), experts involved in solving the problem of risk management use their knowledge and experience in solving similar problems. As a promising direction for further research, it should be noted the development of a methodology for a comprehensive assessment of the effectiveness of operational management decisions for planning and implementing measures to reduce risks.

Keywords: Algorithm, Environmental health, Expert method, Mathematical model, Occupational risk

Introduction

These days are accompanied by significant changes in the socio-economic organization of public life, which contribute to the formation of the market and market relations, rapid industrial progress[1,2] and the emergence of new risks in the workplace.[3] The transition to the active implementation of a risk-based approach is defined by the Concept of reforming the labor protection management system (OSMS) in Ukraine. The construction of such systems, the phased introduction of which will ensure that occupational risk is taken into account when planning preventive measures, provides for a set of theoretical and experimental studies aimed at scientific substantiation of the identification of hazards existing in production and the assessment of occupational risks.

The contemporary principles and methods of risk assessment to a large extent form the basis of improving labor protection management. They have contributed to the achievement of certain successes related to both theoretical research and the practical application of management models and methods.[4-8] However, as practice shows, the choice and rational application of the occupational risk assessment method requires the development of an additional methodology (algorithm) for its practical implementation, as well as a description of data processing methods in the process of planning activities for specific production conditions.

Traditionally, when developing measures to reduce the level of occupational morbidity and industrial injuries, the results of an analysis of the causes, types of events, and other factors that led to accidents are used. But such an approach, as has been repeatedly noted in scientific papers and publications does not meet modern requirements.[8,9] At the same time, the approach to planning events based on the assessment of occupational risks confirms its effectiveness for enterprises of various industries, primarily the most important for the economy of Ukraine (mining and quarrying, production of machinery and equipment, metallurgical production, processing industry)[10], also for certain professions, in particular, drivers of vehicles.[11,12] Risk assessment methods are described in sufficient detail in the international standard IEC 31010:200 "31010:2009 Risk management - Risk assessment techniques" [13] and other standards. Quite a lot of scientific research has been devoted to the study of various aspects and features of these methods, however, these studies do not aim to investigate and solve the problem of operational management of professional risks in the absence of adequate data, and acceptable accuracy.

Therefore, improving worker safety by eliminating accidents involves risk assessment. For an unacceptable and high level of risk, it is urgent to introduce measures to eliminate or minimize the likelihood of a hazard realizing, prioritizing the severity of the consequences. For an average level of risk, a decision is made on the advisability of introducing measures to minimize or eliminate the risk, taking into account the ratio of costs and benefits. An acceptable risk does not require the application of measures to reduce it, but there is a need for constant monitoring to be able to manage the risk.

Establishments should have procedures for identifying existing hazards and assessing occupational risk, which is used in planning and implementing the necessary preventive measures. Methods and methods for identifying and assessing risks must be selected by the characteristics of the workplace, while all types of work and all hazard factors must be taken into account.

The lack of generally accepted techniques (methods, algorithms) that can be used to quantify the risk of injury in the workplace today necessitates the appropriate theoretical and experimental studies. The use of international experience at individual enterprises can significantly improve the state of industrial safety, but there are very few such examples. At the state level, in the absence of generalized databases on working conditions and workplace hazards, the most effective way to assess risks is to study the causes and circumstances of accidents, based on which the justification of preventive measures and the formation of recommendations to reduce risks is carried out.

Workers are affected by production factors of various physical nature, which can be grouped as physical factors (noise, vibration, illumination, dustiness, etc.), factors leading to injuries (worker fall, falling objects, electric shock, etc.), ergonomic factors (order in the workplace, movement routes, escape routes, working posture, etc.). Simultaneous accounting of the whole variety of these factors is in most cases impossible, but even if such accounting is carried out, the question arises: which of the factors poses a danger to the health of workers and what degree of danger does it have? The answer to this question is not obvious, since in real production conditions all the necessary information about possible hazards, methods of processing, and algorithms of actions for making effective decisions are often missing. Since labor protection management is carried out by planning and implementing preventive measures, that is, there must be strict adherence to the hierarchy of prevention and control measures, and a scientific justification for the priority of these measures is required. Unfortunately, one often has to choose, for example, between collective or individual protection measures, and the decision is not always the right one. Some examples from life experience are well described in the work. Also, the existence of a similar problem in various countries of the world is confirmed by initial studies. [14,15,16] Such a justification can be obtained by clearly performing certain actions, that is, an algorithm. Therefore, the purpose of this theoretical study is to improve the decision-making algorithm for effective labor protection management in enterprises. At the same time, it is expected that if the decision-making algorithm is supplemented with certain stages using a modified risk assessment method, then the priority of measures in the management of labor protection will be obvious. Also, the study is expected to receive practical confirmation of theoretical results through their implementation in real production conditions.

Methods

The following methods were used in this study:

1) analysis of modern assessment methods for assessing occupational risks and managing labor protection in the industry in various countries of the world was carried out based on open sources of information, in particular, a search was made in scientific databases PubMed, ScienceDirect, Mendeley, ResearchGate, Google Scholar for relevant keywords. There were no restrictions on the rating of scientific publications. Emphasis was placed on publications in the last 5 years on risk management under conditions of uncertainty, preference was given to publications with the highest citation. However, earlier works, which have useful information for the present study, were also taken into account and were identified in the list of references when studying recent sources. The comparative method and the method of logical thinking were applied to compare existing occupational hazards, the response of workers to various types of hazards, and proposed approaches to risk management in different countries and various industrial enterprises. To analyze the state of labor protection in actually operating industrial enterprises of various industries, consultations were held with fellow practitioners from the expert and technical center of the State Labour Service and the National Research Institute of Industrial Safety and Labour Protection. The consultants were specialists with a fairly large experience (15...20 years) in the analysis of industrial risks and the state of labor protection at enterprises of various types of economic activity. As a basis for such an analysis, first of all, the data of mandatory reporting submitted by enterprises were used. As additional information and analytical documents were used, the results of questionnaires and surveys of certain categories of employees (such documents are usually not subject to publication, but can be used in agreement with the management of the enterprise for analytical research by scientific organizations);

2) synthesis to improve the decision-making algorithm that ensures effective management of labor protection at enterprises;

3) expert evaluation of the weighting coefficients of potential hazards and questioning of employees to accumulate the necessary information about working conditions to practical

testing of the theoretical research results. Noise levels were measured using a mobile application by experts at selected time points. The measurement results were analyzed, if necessary, refined, and recorded on electronic media for further processing. 3 experts were invited:

- Expert 1: deputy director of the enterprise for industrial safety; responsibilities: approval of action plans for labor protection, monitoring the implementation of measures; work experience of about 20 years in the mining industry; occupied the positions of a mining engineer, foreman, site manager;
- Expert 2: a representative of the trade union organization of the enterprise; responsibilities: organizing and conducting training and testing knowledge on labor protection of employees of the enterprise, as well as laboratory studies of working conditions at workplaces; work experience of more than 10 years;
- Expert 3: engineer for labor protection and safety of the enterprise; a young specialist engaged in scientific research on the influence of production factors on the body of workers; work experience - about 2 years; in agreement with the management of the enterprise, collects statistical data on actual noise levels at the workplaces of the enterprise for generalization and further research;

4) mathematical modeling and the modified Elmery method were applied for practical testing of theoretical results.

The well-known Elmery method is based on the observations and results of the actual values of industrial factors (input data) at workplaces, covering all the most important components of labor protection, such as noise, vibration, air temperature at the workplace, etc. Based on the results of the observations, a special questionnaire should be filled out for each workplace, in which one of two estimates can be made for each of the factors: “meets requirements” or “does not meets requirements”. Next, the Elmery index should be defined as the ratio of the number of factors estimated "meets requirements" to the total number of factors.

Advantages of the method: simplicity, visibility, speed, the applicability of the method at enterprises and organizations of any activity field, special skills, and competence are not required. Disadvantage: all factors affecting occupational safety are taken as equivalent (for example, the increased noise level is equivalent to the presence of hazardous chemicals in the workplace). Such an approach to a certain extent simplifies the risk assessment but does not allow for assessing the real state of safety, as well as reasonable planning of preventive and protective measures, taking into account their priority.

In the present study, a modified Elmery method was applied, adapted to the conditions of industrial production of any industry by improving the method of calculating the safety index based on weighting factors.[17] The weight coefficient of each factor is determined as follows. If the actual value of the factor does not exceed the normative one, the weight coefficient will be equal to some minimum value (depending on the accepted evaluation scale). If the actual value of the factor exceeds the standard value, the weighting factor is assigned a value that reflects the potential hazard or danger to the health of workers.

For example, it might look like this: if the actual value of the factor does not exceed the standard value, the weighting factor is equal to 1; if the actual value of the factor exceeds the standard value by 15%, then the level of the weighting factor is equal to 1.15.

For factors, the level of which cannot be determined by measurements, it is proposed to determine their weight coefficients by expert means. Accounting for the specifics of a particular enterprise can be achieved through a flexible mechanism of the questionnaire system, which allows you to include only those factors that are present in the workplace in the studied factors.

Results

It has been established that traditionally planning of labor protection measures is based on an assessment of the production factors levels, and in case of detection of an excess of the actual value over the normative one, the corresponding measure is included in the action plan (figure 1).

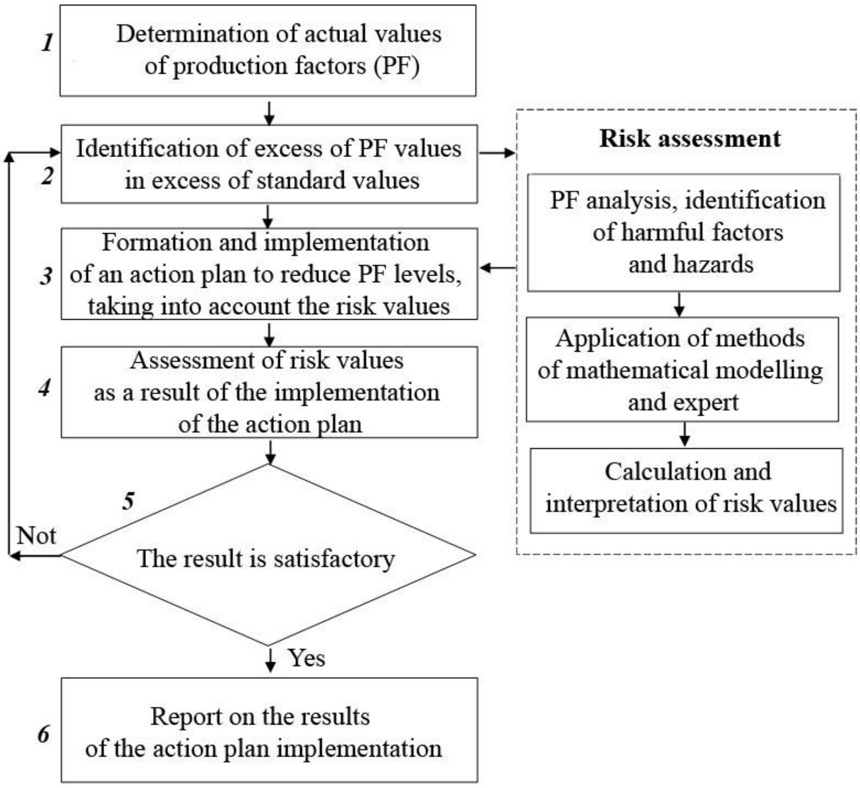

Figure 1. Algorithm for occupational risk managing

That is, the execution of blocks 1...6 of the algorithm is ensured (figure 1). Disadvantages of this approach: a deliberate lack of funds for the implementation of all activities, therefore, a situation is possible when a less significant event is planned and implemented to the detriment of a more significant one.

The improvement of the algorithm (figure 1) compared to the traditional ones is the addition of the "Risk assessment" block. The implementation of the "Risk Assessment" block allows not only to "filter" the activities that do not affect (slightly affect) the risk but also to rank many activities according to the criterion of decreasing their significance in terms of minimizing risks in the workplace.

In practice, the list of activities turns out to be quite large, and its full implementation is impossible due to limited resources (financial, material, human). The task facing the manager (decision maker) is to justify the ranking of measures in descending order of their "importance" in terms of improving the state of labor protection. As a criterion of "importance", it is proposed to use the occupational risk criterion calculated using the modernized Elmery method. The main reason for the modernization of the Elmery method is the need for a differentiated account of each production factor according to the degree of its influence on occupational risk, unlike the classical Elmery method.

An extractive industry enterprise was studied to demonstrate the practical implementation of improved labor protection management. The initial data for planning measures for labor protection are the actual values of production factors at the workplace and the standard values of these factors levels. Data on actual values were determined by direct measurements or questionnaires. The accepted levels of occupational risk gradation and recommended actions (measures) are shown in Table 1.

Thus, a gradation of weight coefficients for each factor is accepted, that is, the range 0...24 corresponds to the state of the factor that meets the requirements of regulatory documents, the state of 75...100 corresponds to the state of a dangerous factor, which can lead to an accident with serious consequences, accidents, etc.

As an example, were considered the results of assessing one of the production factors (noise level) at the workplaces of an extractive industry enterprise (figure 2).

Table 1. Occupational risk gradation levels

Risk assessment		Recommended actions
Limit values (in points)	Name	
75…100	unacceptable	Elimination/risk reduction measures are mandatory and must be initiated urgently Work must be stopped immediately. Start work no sooner than the risk has been eliminated or the degree of risk has been reduced to an acceptable level.
50…74	high	Risk elimination/mitigation measures are mandatory and must be initiated urgently The decision to stop work is made taking into account the ratio of the severity of the consequences of the costs of introducing measures to reduce the risk.
25…49	average	Risk mitigation measures are mandatory but not urgent Compliance with the applicable control measures and the use of regulated safety equipment is mandatory.
0…24	acceptable	Development and implementation of activities is not required The need to ensure constant monitoring of the state of the production environment in order to be able to manage risk

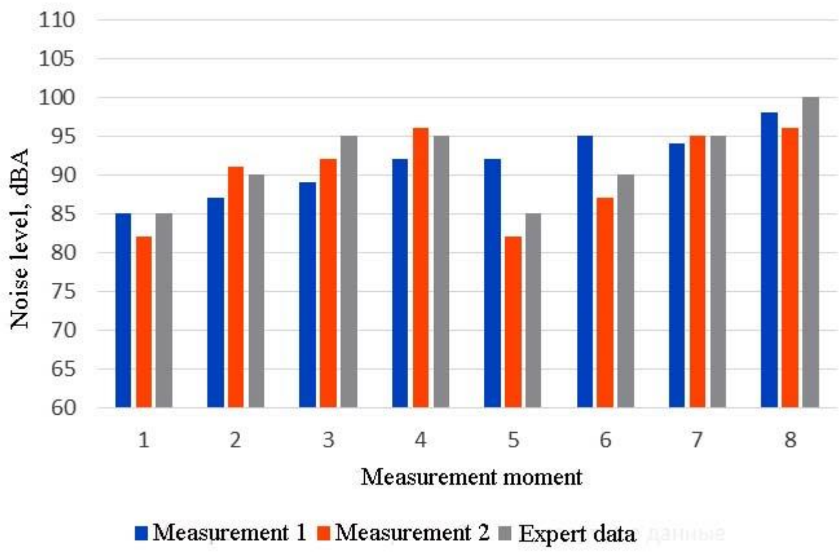

Figure 2. Measurement results and expert assessments of the noise level in the process of production equipment robots

For the study, a workplace was chosen, which is characterized by an increased noise level (exceeding 75 dBA characterizes harmful working conditions). The results were obtained in three ways:

1) "Measurement 1" - measurements were taken using an automated system for monitoring working conditions (allows you to measure several parameters simultaneously with a given discreteness, high accuracy and high costs);
2) "Measurement 2" - measurements were carried out using portable equipment at pre-selected time points in manual or semi-automatic mode (average accuracy, average costs);
3) "Expert data" - measurements were taken by an expert at pre-selected time points using a mobile application installed on a smartphone (average accuracy, minimal costs).

It has been established that the deviation of the values of expert estimates from the measurement results ("Measurement 1") does not exceed 6%. But at the same time, measurement using portable equipment ("Measurements 2") gives an error of only 2%, therefore, to obtain data on the actual values of production factors necessary for the rapid calculation of risks, it is advisable to use this particular option, as the most economical and sufficiently accurate.

Three measurement options (carried out as an experiment) show that it is not necessary to use the most expensive and difficult-to-apply option "Measurement 1".

The average excess of the noise level above the norm is 9.2% (11.5 dBA) (figure 2), which means that the average noise level is 91.5 dBA.

Obtaining the value of the weight coefficient characterizing the noise was carried out as follows. If the noise level is less than Norm (80 dBA), then the factor can be assigned a value in the range 0…25. The maximum possible noise level (for this equipment) is 110 dBA. Then the existing range of 80...110 is divided into 4 classes, similar to that shown in Table. 2: 75…100 (unacceptable); 50…74 (high); 25…49 (medium); 0…24 (acceptable). That is, the noise range 80…87.50 corresponds to the range of weight coefficient values 0…24, the noise range 87.51…95.0 corresponds to the range of weight coefficient values 25…49, etc. Therefore, for a noise level of 91.5 dBA, the value of the weighting factor will be 37.

Similarly, in practice, the values of all other production factors present in the workplace are determined. Further, the calculation of the Elmery index and the occupational risk level is determined by formulas (1) and (2)

$$I_E = \frac{\sum_{i=1}^{n_1} v_i}{\sum_{i=1}^{n_1} v_i + \sum_{j=1}^{n_2} r_j} \cdot 100 \qquad (1)$$

where I_E is the Elmeri index; v_i is the weight coefficient of the factor that determines its impact on occupational risk (for factors whose level meets the requirements of regulatory documents); r_j is the weight coefficient of the factor that determines its impact on occupational risk (for factors whose level does not meet the requirements of regulatory documents, factors that predetermine the risk); n_1, n_2 are respectively, the number of production factors, the level of which meets and does not meet the requirements of regulatory documents.

Then the occupational risk is determined by the formula:

$$R = 100 - I_E \qquad (2)$$

Based on the "Measurement 1" data (as the most accurate), a mathematical model was obtained that establishes the dependence of the noise level (Y) on the time since the start of work (T):

$$Y=-19121.5638 + 855.7325 \cdot T - 14.3567 \cdot T^2 + 0.1070 \cdot T^3 - 0.0003 \cdot T^4. \qquad (3)$$

What is the necessity and benefit of the obtained mathematical model? With a constant technological process, it is enough to carry out only 8 measurements at arbitrary points and, by substituting the values into the model, get the results. If the obtained result coincides (within the margin of error) with the actual noise value (obtained by measuring earlier), then the process is proceeding normally. If there are deviations toward an increase in the noise level, this is a signal to the work manager that it is necessary to take some measures to control the operation of the equipment.

Discussion

The principal feature of the proposed algorithm is the use of predictive risk assessments for planning activities, as the result of the implementation of measures aimed at changing the main indicators of labor protection. Traditional approaches use risk assessments obtained solely as a result of processing retrospective data [18,19], which leads to the use of obviously outdated results and, as a result, to inefficient planning of activities.

Another distinctive feature of the algorithm can be considered the involvement of qualified experts using the available data and information materials (figure 1, Risk assessment block). In conditions of uncertainty, when all necessary (or adequate) data are not available, experts use their knowledge and experience in solving similar problems [20]. In addition, in some cases, qualified experts can assess the levels of production factors [21], which traditionally requires the use of measuring equipment.

The resulting mathematical model in a practical aspect makes it possible to reduce the number of measurements of the industrial noise level to the required minimum (in the current case, once an hour during an eight-hour work shift). At the same time, work can be continued in this case if all labor protection requirements are met: the use of personal protective equipment, strict adherence to work and rest regimes, as well as monitoring of the level of production factors, in particular noise.

The measured value is substituted into formula (3), and the calculation is carried out, after which the calculated value is compared with the existing one. The application of the obtained mathematical model (3), which establishes the dependence of the level of industrial noise from the time the equipment began to operate, can be used in practice to assess the noise level that creates similar (or similar in technical characteristics) equipment. In this case, it should be taken into account that if there are changes in the technological process, the replacement of raw materials, etc., then the resulting model should be refined. To do this, it is necessary to re-measure noise levels at certain time intervals and build a new model based on the data obtained. Practical experience shows that the general appearance of the new model will not differ significantly from the existing one if the changes in the technological process were insignificant. But, if the technology or other factors of production have undergone significant changes, then, obviously, the type of model will also differ significantly from the type of model obtained earlier.

The construction of mathematical models and the calculation of predictive estimates of occupational risk (as a result of the implementation of planned activities, stage 5 of the algorithm) is based on the assumption that the level of occupational risk at each time t is characterized by the value defined in the task of managing this indicator. This indicator depends on the values of the plural number of factors of the state of labor protection at the previous point in time (t-1) and the expected results of the implementation of the adopted managerial decision:

$$R_i = F(X_t, Q_i) \qquad (4)$$

where R_i is a mathematical model that establishes a relationship between the risk value and a set of production factors (the values of which correspond to the time t); Q_i is management decision (action plan) $Q_i = \{q_1^i, q_2^i, q_3^i, \ldots\}$.

The formation of various options for action plans is carried out based on the processing of available statistical data, with the use of expert and analytical support. First of all, from the pre-formed set of activities Qi, those activities are excluded, the implementation of which at the time of the decision (t) is impossible due to the lack of any resources (human, financial), insufficient level of performance discipline, lack of time, etc. Further, the set of measures must be sorted so that each action (for example, q_1^i) allows reducing the risk by an amount not less than the next action (q_2^i). Recommended for selection will be an action plan that will allow for the reduction of the occupational risk value calculated by the formula (3) to the maximum extent.

To conduct experimental studies, taking into account expert assessments, three action plans (Q_1, Q_2, Q_3) were formed that implement different strategies for managing labor protection in an extractive industry enterprise. Further, with the use of mathematical models, the calculated values of risk reduction for each activity were obtained, the results are presented in figure 3.

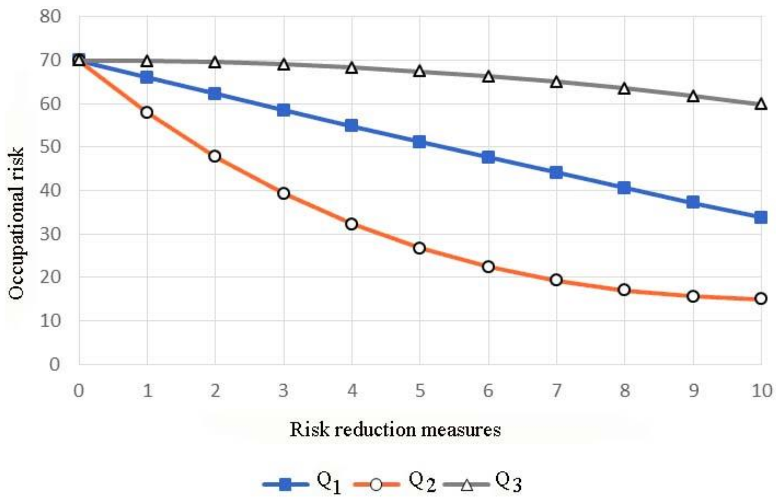

Figure 3. Graphical interpretation of the dependences of the level of occupational risk on the results of the implementation of labor protection measures

As is obvious from figure 3 in the considered case, the best is the action plan Q_2, which will be accepted taking into account the calculations of the expected decline in professional levels (block "Risk assessment" of the algorithm, figure 1). Plans Q_1 and Q_3 were taken without regard to risks.

In addition, the obtained dependences can be expressed by power polynomials. In particular, the mathematical model that establishes the dependence of the level of occupational risk (R) on the results of the implementation of labor protection measures (Q_2) has the form of a polynomial of the 3rd degree:

$$R(X, Q_2) = 70 - 12.9819 \cdot Q_2 + 0.9815 \cdot Q_2^2 - 0.0234 \cdot Q_2^3 \quad (5)$$

The use of the obtained dependencies of occupational risk on the results of the implementation of labor protection measures can be useful at the planning stage of measures since by substituting specific values of the corresponding numbers of measures into the formula, you can get the expected risk assessment. If the decision-making situation is characterized by conditions of uncertainty (it is impossible to obtain mathematical models of acceptable accuracy), the assessment of the predictive values of occupational risk is carried out exclusively by an expert. [22,23]

Thus, the occupational risk indicator used at the final stage of planning activities determines the degree of achievement of the result of solving the task.

Ways to solve problems

As can be seen from the presented algorithm, the transition to new technology for the development, adoption, and evaluation of management decisions involves the implementation of the functions of scientific support for management activities through the integrated use of modern information technologies, mathematical modeling, forecasting and expert methods. At the same time, it should be noted that decision-making under traditional and new management technologies remains the prerogative of the manager responsible for solving the task.

The implementation of a management decision to reduce risks has many qualities. The economic aspect is that the development and implementation of any management decision require resources. The organizational aspect is that for effective work on the adoption and implementation of decisions, it is necessary to appoint one or more executors, endowed with rights, duties and responsibilities, as well as to allocate the necessary (financial, material, human) resources. The social aspect implies the existence of an effective mechanism for managing performers based on motivation. The legal aspect consists of strict compliance with the requirements of the current regulatory legal and legislative acts, as well as other documents that must be taken into account in the process of implementing the decision.

Conclusion

An occupational risk management algorithm is proposed for use in the field of labor protection, which provides for the implementation of the stages of development, adoption and evaluation of the effectiveness of management decisions on planning and implementing measures. The algorithm is based on the use of databases on the state of labor protection, as well as methods of statistical data processing, mathematical modeling and forecasting, and expert assessments. For an adequate assessment of occupational risks, it is necessary to have objective data from different periods: the onset of traumatic events in the past, the current state of threats to the life and health of people, and the future state of threats. At the same time, in conditions of uncertainty (lack of necessary data or available data are incomplete or unreliable), experts involved in solving the problem of risk management use their knowledge and experience in solving similar problems.

The resulting mathematical model in a practical aspect makes it possible to reduce the number of measurements of the industrial noise level to the required minimum (in the current case, once an hour during an eight-hour work shift). At the same time, work can be continued in this case if all labor protection requirements are met. The application of the obtained mathematical model (3), which establishes the dependence of the level of industrial noise from the time the equipment began to operate, can be used in practice to assess the noise level that creates similar (or similar in technical characteristics) equipment. Practical experience shows that the general appearance of the new model will not differ significantly from the existing one if the changes in the technological process were insignificant. But, if the technology or other factors of production have undergone significant changes, then, obviously, the type of model will also differ significantly from the type of model obtained earlier.

As a promising direction for further research, it should be noted the development of a methodology for a comprehensive assessment of the effectiveness of operational management decisions for planning and implementing measures to reduce risks, [24] especially if experts have to work under stressful conditions for long periods, which will contribute to their fatigue. [25]

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