Досліджено можливості усунення або зменшення рівня професійних ризиків. Запропоновано новий підхід до процедури ідентифікації та оцінки виробничих ризиків. У розробленому алгоритмі, на відміну від існуючих, впроваджено показник шкідливих та небезпечних виробничих факторів і структурований етап оцінки ризиків, який надасть можливість підвищити точність визначення рівня виробничих ризиків на гірничих підприємствах

Ключові слова: фактори виробничого середовища, виробничий травматизм, професійна захворюваність, управління професійними ризиками

Исследованы возможности устранения или уменьшения уровня профессиональных рисков. Предложен новый подход к процедуре идентификации и оценки производственных рисков. В разработанном алгоритме, в отличие от существующих, введен показатель вредных и опасных производственных факторов и структурирован этап оценки рисков, который позволит повысить уровень определения производственных рисков на горных предприятиях

Ключевые слова: факторы производственной среды, производственный травматизм, профессиональная заболеваемость, управление профессиональными рисками

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DEVELOPMENT OF THE UNIFIED TECHNIQUE FOR THE MONITORING OF OCCUPATIONAL HAZARDS AT KRYVBAS MINING ENTERPRISES (UKRAINE)

D. Zaikina
Postgraduate student
Department of the mining aerology and the occupational health and safety
Kryvyi Rih National University
V. Matusevych str., 11, Kryvyi Rih, Ukraine, 50027
E-mail: zayckina.darya@yandex.ua

1. Introduction

Workers of mining enterprises are under the impact of numerous hazards. There is a real threat to the health of workers and a great risk of occupational injuries.

A unified methodology for the identification and assessment of risks will minimize the likelihood of accidents, occupational diseases and accidents at work. Health protection is a necessary condition for the economic and social well-being of the country.

Risk assessment enables to avoid significant financial costs to eliminate the impact of hazardous events and uplevel the stability of performance of production tasks at mining enterprises.

The developed unified methodology can contribute to accumulation of databases for quantitative and qualitative characteristics of occupational hazards (hereafter OH) in different socio-technical systems of production activities. The unified methodology, in the same number of the hazard-determining factors will provide comparative OH assessments for mining enterprises.

Therefore, the relevance of the unified methodology for monitoring occupational hazards lies in:

– risk identification and objective assessment, including by the quantitative indicators;

– ensuring the economic value-added choice;

– the application of reasonably practicable measures to minimize the risk of injury in the workplace.

The above-mentioned determines the necessity and urgency of the unified methodology of assessment of occupational hazards as one of the directions of optimization of occupational health and safety management system. This is primarily due to the fact that the number of occupational hazards at the workplace increases every year.

2. Literature review and problem statement

In [1–3] basic attention is given to the study and research evaluation of working conditions improvement. A number of measures are proposed in order to ensure industrial safety, which gives the opportunity to preserve the health and working ability of a person at the workplace.

In [4–6] health, safety and security management issues are examined. The authors [4–6] note that the safety of every employees is the problem of:

– economic;

– social value.

Therefore, safety issue must be in the center of attention of specialists of all the structural units and services of an enterprise.

Risk management includes development and implementation of economically reasonable recommendations and activities for an enterprise, which are aimed at reducing the risk level to an acceptable final level. This gives you the opportunity to identify priority areas for efficient planning of occupational health and safety.

The authors [4–6] have noted that the creation of a unified system of indicators in the field of occupational health and safety is to improve national labor laws and improve working conditions through the implementation of international technical cooperation programmes.

Basic approaches to the management of industrial risks are in scientific studies [7–9] and provide general regulations of occupational health and safety situation in Ukraine and the EU countries. It is extremely important that these approaches and principles allow improving international cooperation and introducing common European standards of risk assessment.

In [10–12] risk was defined as:

– the result of different kinds of reasons: technological, organizational, social and economic;

– the probability of dangerous and harmful operational factors of man-machine-environment configuration (equipment, technology and type of production, factors of production environment, the severity and intensity of work, work organization, professional training of employees) that influence the safety level.

All definitions are reduced to the fact that risks are formed by two quantities – the probability of a negative events and the amount of damage from it.

In scientific papers [13, 14] risk assessment techniques are examined (further RAT) in the field of occupational health and safety. In [13, 14] the authors draw attention to the dependence of dangers on various factors of production environment and have made conclusions that the problem of the risk management is related to:

– the identification of hazards;

– the definition of possible damages to the worker's health and the probabilities of their occurrence;

– the presence of sufficient statistical information for the calculation of the required risk rate – the basis for choosing direct RAT [15–17].

The main of them include [15–17]:

– the British Standard BS-8800 (UK);

– RAT based on the "probability-damage" matrix (UK, France, Latvia, the US, Australia);

– the method of building the risk assessment graph (Germany, Finland);

– the methodology of the National Research Institute Industrial Safety and Health (NRIISH) in Ukraine);

– the Risk assessment code methodology (United Kingdom);

– the method of verbal functions (European Union).

The indirect techniques of the workers' health and life risk assessment use the indicators characterizing the deviation of current (controlled) conditions (parameters) from the rules and have a cause-effect relationship with risks. They don't involve the direct detection and identification of hazards in the workplace and in the performance of production activities.

The main indirect RATs in the field of occupational health and safety are:

– an occupational risk assessment technique according to the Elmer method;

– a risk assessment technique based on ranking of the level of requirements (IAD index).

The IAD index, as well as the Elmeri index, is not directly associated with the presence and assessment of specific risks in the workplace [15–17].

Thus, companies and organizations use a variety of risk assessment methods and combinations thereof. But often, these methods do not include all the criteria of the individual and collective risks, which makes it impossible to choose a RAT that would be most suited to the specifics of an enterprise [18, 19]. This suggests the need for research in this area.

Also, currently in Ukraine there is no legal framework that would regulate the risk assessment methodology in the area of occupational health and safety in the conditions of mining enterprises. There are only scattered recommendations on this issue, and it is suggested to apply:

– one technique to cover all the existing risks in a particular workplace;

– several techniques for different parts of the workplace.

In order to achieve the main goals of occupational health and safety management based on evaluation of OH, occupational health and safety divisions at mining enterprises should better study modern assessment methods of risks faced by such enterprise.

Thus, the main problem with risk assessment in the area of occupational health and safety is the lack of a unified methodological approach, which is based on the standard provisions, uniform conditions and methods of assessment of working conditions.

3. The aim and tasks of the study

The aim of this work is to create a unified technique for monitoring occupational hazards of mining enterprises, or otherwise, automated information and measuring system of permanent monitoring, diagnosis of the level of occupational health and safety.

To achieve this aim, it is necessary to solve the following problems:

– to propose a new approach to assessing the efficiency of occupational health and safety management systems on the basis of the occupational hazard management concept;

– to develop an algorithm for evaluation of the occupational health and safety management system.

4. Development of the unified technique for the monitoring of occupational hazards at the mining industry enterprises in the occupational health and safety management system

For the possibility of hazard management, it is necessary to calculate the magnitude. The structure of a risk includes the following elements, which are supposed to be general for all types of hazards:

– the severity of consequences (injury severity);

– the probability (qualitative characteristic of the hypothetical frequency of dangerous situations);

– the prescription of an accident (occupational accident or disaster);

– the risk influence duration (according to the number of hours of hazardous influence on a worker per shift);

– the risk influence time interval (length of service, age).

An important problem in the risk assessment is the account of exposure, that is the impact of not only the level, but also the duration of influence of harmful working conditions. In current working conditions, the harmful factor influence duration or influence time interval is often unknown. The magnitude of the effects of harmful factors may be the length of service. Because throughout the period of work activities, the worker's health is affected not only by random variations of the main harmful factor, but also the whole complex of other concomitant factors. The need for the accounting of working age is caused by the direct dependence of the length of service, age and working capacity. In other words, compensatory capacity of the organism are reduced with age, which on the background of poor working conditions may become one of the causes of certain psychophysiological disorders in employees. Therefore, the age parameters are always used for differential diagnosis of changes in health in order to address the problem of a cause-effect relationship of health, age and length of service of an employee.

Research has established that the development of the basic part of occupational diseases accounted for the length-of-service group with the duration close to the interval from 10 to 15 years. Evaluation of the probability of disability allows us to use a 10-year seniority as a reference point.

Therefore, for the analysis of the relation of age and length of service in harmful and (or) dangerous working conditions to the level of individual occupational hazards, the following characteristics were introduced:

– age category of workers, (A);

– length of service in harmful and (or) dangerous working conditions, (W).

The risk matrices (Table 1, 2) will allow forming five age and seniority groups of workers. Gradation of possible scenarios concerning the severity of consequences and the probability of events in such matrices is usually carried out over 3–5 ranges. This takes into account the nature of the damage caused to health, from easy to an extremely harmful, as well the parts of the worker's body that are prone to injury. Usually, the hazards in the matrices are classified into low, medium and high.

Table 1

The value of the indicator of a certain seniority of workers

Serial number of the indicator of a certain seniority of workers, (W)	Number of a seniority group
1	0–10
2	11–15
3	16–20
4	21–25
5	25 – more

Table 2

The value of the indicator of a certain age group of workers

Serial number of the indicator of a certain age group of workers, (A)	Number of the age group
1	18–29
2	30–39
3	40–49
4	50–59
5	60–69

Definitely, the advantage of the risk gradation matrices (further RGM) is the opportunity of a maximum coverage and estimation of potentially dangerous events in a single measure (scale) for an enterprise in general. Based on the results of the risk assessment, the measures to reduce risks are planned.

Since a large number of workers often suffer occupational accidents, it is possible to speak about individual and social risks.

The index of the individual risk level at an enterprise (by a separate hazardous professional factor or the complex of harmful occupational factors in each professional, age or seniority group of workers) is determined by the formula [12]:

$$R(F)=100/((1+\exp(4((F-F\_k))/\Delta F)), \qquad (1)$$

where F is the value of the level of an influencing factor. According to Tables 1 and 2, the influencing factor can be represented as an estimated index for a certain seniority of workers (W), or as an estimated indicator of the age group of workers (A); F_k is the critical value of the parameter F, for which R(F)=50 %; ΔF is the measure of the value range of the parameter F, within which there is a sharp increase in the risk probability.

At the same time, the degree of a social risk at an enterprise (in general) [14] is calculated by the following formula:

$$R = S\times P\times Pr\times D\times E, \qquad (2)$$

where S is the coefficient of significance of the accident consequences; P is the coefficient of the accident probability; Pr is the coefficient of remoteness of events (accident and/or occupational disease); D is the coefficient of the duration of danger impact (accident); E is the factors that influence the risk of accidents and/or occupational diseases.

The consequence of the impact of OH, identified at the workplace, which is the possibility of injury and/or deterioration of health, is subject to the procedure for determination of the risk size according to RGM (Table 3–7).

Determination of the significance coefficient (S) depending on the severity of the consequences depends on the following (Table 3).

Table 3

The significance coefficient, (S)

Value of the significance coefficient, (S)	Characteristics of influence, (S)	Comments
1	Minimal impact	Minor injuries (scratch, hematoma, small cut). An injury that does not need any medical care and/or allows working after first aid
2	Moderate impact	Easy consequences without long-term (less than a week) disability. Injuries leading to temporary disability of an employee (fracture, contusion, electric shock, burns)
3	Significant impact	Severe injury (eye injuries, open fractures, etc.). Serious consequences with/without long-term (more/less than two months) disability. An acute or a chronic occupational disease (with the possibility of further work in another specialty). Serious consequences that exclude the possibility of employment. A special investigation is required
4	Substantial impact	A fatal accident. A special investigation is required
5	Catastrophic impact	Group accident with/without fatal consequences. A special investigation is required

To determine the probability of damage, the available information about accidents and occupational diseases is compared (Table 4). The level of probability, which corresponds to the frequency of the expected event (consequences with established severity degrees) [13, 14, 18, 19] is usually chosen.

Table 4

The probability of possible harm, (P)

The value of the probability coefficient, (P)	% of the probability, (P)	Probability features	Comments
1	0.0001	Unlikely	No accidents for 10 years of work
2	0.01	Minor probability	1–2 accidents for 10 years of work
3	1	Probably	3–4 accidents for 10 years of work
4	10	Very likely	5–9 accidents for 10 years of work
5	50	High probability	An accident happens every year, regularity of accidents is observed

The coefficient of prescription of an accident (Pr) is determined according to Table 5.

Table 5

The coefficient of prescription of an accident (Pr)

The value of the coefficient of prescription of an accident, (Pr)	Prescription parameters
2.0	The latest accident happened 1 year ago or less
1.9	The latest accident happened 2 years ago
1.8	The latest accident happened 3 years ago
1.7	The latest accident happened 4 years ago
1.6	The latest accident happened 5 years ago
1.5	The latest accident happened 6 years ago
1.4	The latest accident happened 7 years ago
1.3	The latest accident happened 8 years ago
1.2	The latest accident happened 9 years ago
1.1	The latest accident happened 10 years ago
1	The latest accident happened over 10 years ago or accidents are absent

The duration of the threat (D) is determined by the number of hours of the hazard impact on an employee per shift, according to Table 6.

The factors that influence the risk of accidents and/or occupational diseases are determined according to Table 7.

The value range of the industrial hazard indicators (the IHI) for classes of conditions at the workplace is calculated depending on the degree of hazard and danger of industrial factors. Comprehensive estimation of factors of production environment and the degree of hazard and danger of work is established on the basis of safety classification of work and the results of the assessment of workplaces.

In order to assess individual and social risks at an enterprise, changes in indicators of harmful and dangerous industrial factors (the IHDIF) at a workplace were considered [16, 20]. The results of the analysis and calculated values of IHDIF received in workplaces with harmful conditions are given in Table 7.

Table 6

The duration of the threat, (D)

The value of the coefficient of impact duration, (D)	Comments
1	Continuous threat impact on employees is absent (impact of potential hazards not related to production processes)
2	The threat impact on employees lasts less than 2.5 hours per shift
3	The threat impact on employees lasts 2.5–5 hours per shift
4	The threat impact on employees lasts more than 5 hours per shift

After determining the value of OH, threats with the highest risk are singled out according to Table 8 [13, 14].

To make a complete assessment of the state of occupational health and safety at operational and production areas, it is also recommended to use a generalized coefficient of the level of occupational health and safety K_op, which is defined by the formula [21]:

$$K\_op = ((K\_pb + K\_b + K\_vpr + K\_pt)) / 4, \quad (3)$$

where K_pb is a coefficient of compliance of workers with occupational health and safety rules; K_b is a coefficient of the technical security at an enterprise; K_vpr is a coefficient of performance of planned activities in the area of occupational health and safety; K_pt is a coefficient of losses due to the occurrence of industrial injuries.

With increasing loss of working capacity in relation to the level of the previous period, i. e. K_pt >1, the coefficient K_pt is taken with the sign “–”. With reducing loss of working capacity, i. e. K_ pt<1, the coefficient K_pt is taken with the sign “+”.

The coefficient of the level K_pb, that is compliance of workers with occupational health and safety rules is calculated by the formula:

$$K\_pb = P\_n / P, \quad (4)$$

where P_n is the number of workers who follow occupational health and safety rules; P is the total number of workers.

To determine K_bp, a card of the level of occupational health and safety rules observance at the operational area, at an enterprise, in general, is introduced and the number of the workers who follow occupational health and safety rules is estimated.

Table 7

The indicators of harmful and dangerous industrial factors, E

The serial level number, E	The value range of the factors that affect the risk of accidents and/or occupational diseases	Characteristics of harm and hazard impact	Comments
1	2	3	4
Parameters of harmful and dangerous industrial factors			
Dust, mg/m^3 (at a maximum allowable concentration of 2.0 mg/m^3)			
1	<5	Minimal impact	Auscultation, at first, reveals hard breathing, which gives way to weakness because of emphysema growth; wheezing appears. A disease is caused by a slight but lasting and permanent contact with an allergen. Slowly progressive process of disease lasts for 20 years or more, sometimes the process is stabilized
2	15	Moderate impact	A rapidly progressive process of disease at less intense impact – 10 years
3	25	Substantial impact	A disease is characterized by moderate pulmonary fibrosis, benign and slowly progressive course; it is often complicated by a nonspecific infection, chronic bronchitis, which usually determines the severity of a disease
4	35	Significant impact	A disease tends to the progression of the fibrotic process and can be complicated by a tuberculosis infection
5	>35	Catastrophic impact	Regressive pneumoconiosis. With high concentrations of dust and high level of quartz in it, the progression of the process, where the transition from one stage to another lasts for 4–5 years. Among those who eventually left the production, the progression is stated only in 10–20 % with silicosis of the stage I and almost 100 % with the stage III. Pneumoconiosis can be formed even after the termination of work under harmful conditions (a «late» process of disease). It often differs in these cases by a further unfavorable course. Quartz contact termination does not always delay the process, but the quicker the contact is terminated the less chance for progression is possible
Noise, dBA (at the maximum allowable level factor of 80 dBA)			
1	85	Minimal impact	Short-term and intensive impact on the hearing organ can cause complete loss of hearing due to the destruction of the hearing aid. Hearing loss of the 2nd and 3rd degree may develop (under the 8-hour impact). With the work duration of 39 and more than 45 years, the probability of hearing loss is 10 and 25 %. With the work duration of 10–15 years, it's correspondingly 3–5 %
2	90	Moderate impact	Loss of hearing in sound frequencies of 500, 1,000 and 2,000 Hz, dB (the arithmetical mean). With the work duration of 35 and more than 45 years, the risk of hearing loss amounts to 10 and 25 % (criterion of less than 20 dB). The work duration of more than 45 years includes a 50 % chance of hearing loss (criterion of less than 30 dB). The risk of damage to hearing by noise is 10–14 %, with the work duration of 10–15 years
3	95*	Substantial impact	The cochlear neuritis with a mild level of hearing decrease. The risk of hearing loss under the noise influence over 10 years amounts to 17 %, and the probability of hearing loss is 31 % with the work duration of 39 years
4	100	Significant impact	The cochlear neuritis with a moderate degree of hearing loss. The risk of hearing loss under the influence of noise over 10 years amounts to 29 %
5	>100	Catastrophic impact	The cochlear neuritis with a significant degree of hearing loss. As the result of high intensity of noise, such systems can be simultaneously damaged: the cardiovascular system, neuroendocrine and immune systems. The risk of hearing loss under the noise impact over 10 years amounts to 71 %
Vibration, dB (at an acceptable limit of the safety factor of 107 dB)			
1	107	Minimal impact	It is characterized by low severity of symptoms. The nervous excitement with depression. The process is still quite reversible. Under the impact of low-frequency vibration, the disease occurs after 8–10 years (drillers)
2	109	Moderate impact	Hand pain and paresthesia, the vibration sensitivity threshold decrease. In addition to vasculomotor disorders, such symptoms as pain spread throughout the hand, hypothermia, cyanosis and hyperhidrosis of hands can also appear

Continuation of Table 7

1	2	3	4
3	111	Substantial impact	It is characterized by severe vascular disorders with attacks of vasospasms and tissue blanching (the acroasphyxia), followed by capillary paresis. Also, changes are observed in the functional state of the CNS, cardio-vascular system, endocrine system, metabolism. Disease occurrence is possible
4	113	Significant impact	It is characterized by generalized vascular disorders, including coronary and cerebral vessels. It causes vibration disease
5	>113	Catastrophic impact	Long-lasted and intense effect on a person leads to disorders of the nervous system, dizziness and headache, visual disorders, numbness and finger swelling, joint diseases, sensitivity loss, and other pathological changes. Development of finger-phalange gangrene is possible
*Parameters of the microclimate***			
Temperature, °C (standard of 26 °C at the working place, at a maximum allowable) during winter time			
1	26.6	Minimal impact	Heat losses are decreased due to convection and radiation, but they are increased because of evaporation
2	27.4	Moderate impact	Under conditions of thermal radiation, the heat output by a body is complicated. As the load increases during the working process, there is an accumulation of heat in the body, resulting in unproper regeneration of physiological functions. This state is caused by stress or even overstrain, characterized by tachycardia during the work, an increase of lung ventilation, power and water expenditure per shift. As a result, productivity decreases
3	28.6	Substantial impact	Characterized by a decrease of productivity by 40 %. The process of adaptation to the hot environment is very difficult. Some people cannot adapt to the conditions even after 3–5 years of work. It causes a high risk of occupational injuries. Work in the conditions of hot environment is contraindicated in people with vegetative-vascular dystonia, arterial hypertension, coronary heart disease
4	31.0	Significant impact	Continuous or permanent presence in the environments with the temperatures over 26–28 °C, air humidity level over 80 % and air velocity less than 0.3 m/s. Characterized by chronic overheating. Among the workers, whose work is associated with a significant physical activity, an intense biological aging is observed, especially in the age groups of 20–30 and 40–50 years
5	>31.0	Catastrophic impact	When the air temperature equals to the body temperature, the heat transfer at the expense of radiation and convection is almost gone. The only way to heat elimination is sweat evaporation. This kind of the microclimate of modern deep-level mines increases the risk of workers' deaths because of cardiovascular diseases. The symptoms of the body overheating of a worker are headache, excessive sweating (over 200 g/h) and functional impairment of the respiratory system, fatigue, which decreases the body resistance to a disease
Relative humidity, % (at occupational exposure standards of 40–60 %)			
1	>60 %	Minimal impact	The inability to perform hard work at high temperatures (≈30 °C)
2	70 %	Moderate impact	Extremely harmful air humidity at a temperature of 30 °C and more. The heat transfer by radiation and convection is very complicated because of little difference between skin temperature and ambient temperature
3	75 %	Substantial impact	Negative effect on the body and the heat transfer
4	80 %	Significant impact	In combination with high temperatures, the rate of brain activity is reduced by half, concentration and attention drop sharply, the number of errors increases 5–6 times. Body temperature increases. Occupational diseases occur
5	>80 %	Catastrophic impact	The combination of humidity with high temperatures leads to significant accumulation of heat in the body. Hyperthermia occurs (a condition in which the body temperature rises to 38...39 °C). At low temperatures, humidity increases the heat transfer from the skin, leading to hyperthermia. The threat to the health & risk of occupational diseases. The limit of the employee's heat balance is the air temperature level of 30 °C, and humidity level of 85 %

*Note: relative air humidity varies from 70–80 % in shaft bottoms to 90–100 % at the end of breakage face, where workers are constantly present within the limits of 0.25–8 m/s; * – the problem is that sometimes the perception of speech and warning signals can be complicated by the means of hearing protection. This happens mostly in the cases, where users are already suffering from hearing impairment and the noise level drops below 90 dBA; ** – given ranges of temperature and relative humidity values correspond to the results of the air-temperature survey*

Table 8

The value of OH, (R)

The value of occupational hazard, (R)	Characteristics of OH
1–11	Low risk
12–32	Medium risk
33–80	High risk
81–200	Highest risk

The coefficient of safety K_b of an equipment unit is calculated by the formula:

$$K_b = T_o / T_b, \tag{5}$$

where T_o is the number of workplaces and equipment units; T_b is the number of workplaces and equipment units that correspond to the occupational health and safety requirements.

To monitor the safety level of the production equipment in the field (at the operational area), there is the safety coefficient of the field K_{bo}, operational area K_{by} and departments K_{bp}:

$$K_{bo} \text{ and } K_{by} = \frac{K_{bn1} + K_{bn2} + \ldots + K_{bnm}}{m}, \tag{6}$$

where $K_{bp1}, \ldots, K_{bpm}$ are the safety coefficients of departments; m is the number of departments in the industry (at the operational area).

$$K_{bp} = \frac{K_{b1} + K_{b2} + \ldots + K_{bpn}}{n}, \tag{7}$$

where $K_{b1}, \ldots, K_{bn}$ are the safety coefficients of the equipment units operated (the workplaces); n is the number of equipment units in the department.

The coefficient of performance of planned activities in the area of occupational health and safety K_{vpr} is defined by the relation of:

– the number of actually performed activities and actions foreseen for the given period of time by the plan of activities of chief managers, middle managers and other specialists;

– duties on social issues and occupational health and safety in the collective labour agreement;

– requirements of state supervisory authorities or parent organizations and the occupational safety and health department of an enterprise;

– measures for accident cause elimination that are specified by the acts N-5 and N-1;

– orders, regulations, and instructions of an enterprise.

To calculate the coefficient K_{vpr}, a card of performance of planned activities is made:

$$K_{vpr} = M_b / M_n, \tag{8}$$

where M_b is the number of activities completed; M_p is the number of means that are provided by relevant documents.

The coefficient of losses due to industrial injuries is defined by the formula:

$$K_{pt} = \frac{(K_{ch}) \times K_t}{K_{cho} \times K_{to}}, \tag{9}$$

where K_{ch} is the frequency rate of occupational injuries during the reporting period; K_t is the severity rate of occupational injuries during the reporting period; K_{cho} is the frequency rate of occupational injuries during the previous period; K_{to} is the severity rate of occupational injuries during the previous period.

The injury frequency rate K_{ch} is represented by the relation of the victims number to the average number of workers for the given period, related to 1000 workers:

$$K_{ch} = (N_1 / N_r) \times 1000, \tag{10}$$

where N_1 is the number of victims who are disabled for a period exceeding three working days and fatal ones; N_r is the number of workers for a particular period of time.

The injury severity indicator K_t characterizes the average duration of temporary disability of injured workers and is determined by the formula:

$$K_t = \frac{D_n}{N - N_{sm}}, \tag{11}$$

where D_n is the number of man-days of disability of all victims for a particular period; N is the number of victims who are disabled for a period exceeding three days; N_{sm} is the number of deaths in case of an accident.

The loss indicator of working time per 1000 employees for a specific period of time (a year) more completely describes the injury rate in the industry. It is determined by the formula:

$$K_p = (D_n / N_r) \times 1000. \tag{12}$$

Based on the be aforementioned criteria, it is advisable to make an algorithm and determine the effectiveness of the occupational health and safety management system.

The exact expression to determine the level of effectiveness of the occupational health and safety management system (HSEMS) is as follows:

$$EPH_{OHSEMS} = \frac{ESV}{R \times K_{op}}, \tag{13}$$

where ESV is a unified social tax for the obligatory state social insurance [16]; R is a degree of the individual risk at an enterprise (by a specific or several hazardous occupational factors in each professional, seniority or age group of workers). In determining the general condition of occupational health and safety, the degree of social risk at an enterprise should be used; K_{op} is a generalized coefficient of occupational health and safety.

Consideration of all the above-mentioned indicators allows assessing condition of occupational health and safety at mining enterprises in a proper way.

5. Discussion of the results of the unified methodology research for monitoring occupational hazards at mining enterprises

The algorithm is done on the basis of the data analysis for the period of 2008–2016 [22–26]:

– reporting and accounting materials on injuries, occupational diseases (acts on form N-5 and N-1, P-5);

– materials concerning all types of occupational health and safety control;

– data of sanitary and technical certificates of objects and workplaces;

– results of aerial and temperature surveys.

Based on the above-mentioned information, an algorithm of management of occupational hazards is proposed (Fig. 1). The given method that allows assessing risks at a workplace (and an enterprise in general) includes the following basic stages:

– description of a risk, identification of threat sources (hazardous production facilities, kinds of production activities, products, professions, equipment, contract works, etc.);

– identification of threats, determination of causes and consequences;

– determination of the causes and consequences, selection of the methods of influence on a risk, data collection, risk calculation;

– achievement of the acceptable (permissible) risk level;

– taking additional measures to reduce a risk to an acceptable level;

– re-analysis and review of risks at an enterprise;

– development of risk management measures;

– efficiency analysis of the developed risk management measures (in case of negative results, studies are carried out on the possibility to eliminate or reduce a risk, develop the procedure (plan) to eliminate or decrease a risk, choose the method for the risk management);

– monitoring of the activities performed.

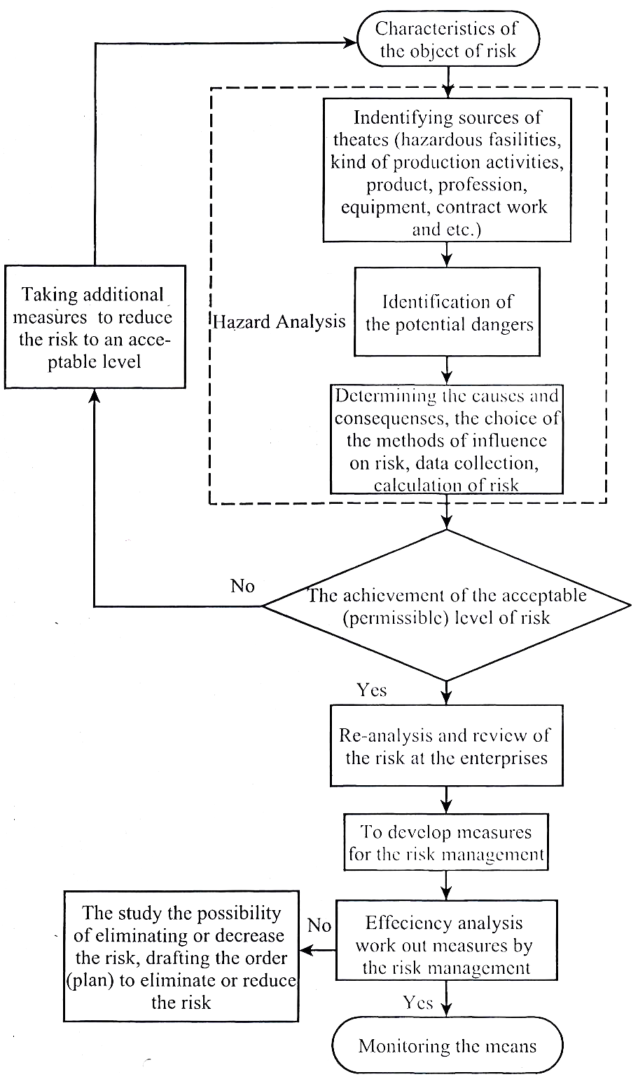

Fig. 1. Algorithm for occupational risk management and determination of dangerous workplaces using a priori information

To determine the adequacy of the proposed risk assessment methodology, data of occupational accidents and occupational diseases at enterprises of Kryvbas region were studied [22–26]. The dependence of disability on the time interval of the risk impact was found (Fig. 2) [27].

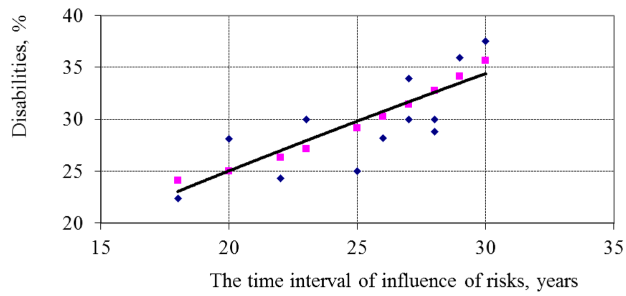

Fig. 2. Graph of the workers' disability and the time interval of the risk impact

The developed method allows determining the collective and individual occupational risks, including the dependence of exposure, generalized coefficient of occupational health and safety situation and risk level.

The introduction of the unified risk assessment methodology gives a chance to improve the level of works on prevention of accidents and occupational diseases, to strengthen control over the observance of labor protection regulations at enterprises of the mining industry [22–26]. At the same time, the social effect is expressed in a decrease in the number of employees working under the conditions that do not meet the requirements of industrial safety and sanitary standards and makes up 11 % [22–26].

The advantage of the developed technique is:

– accessibility and ease of calculation;

– the possibility of taking into account the whole complex of risks;

– determination of the risk level through the probability of any negative event.

The disadvantages of the technique include:

– the need to determine the exact list of possible interacting risk factors, which can be extensive. Otherwise, there will be a need to assess the cumulative impact of all factors, which is quite difficult;

– the complexity of determining the impact of risk factors on the investment results;

– the complexity of assessing the probability of an event that determines the effect of a specific risk factor.

Adoption of the new concept as a promising direction of development of relations in the field of labor protection in Ukraine will allow improving the situation at mining enterprises of Kryvbas region.

Thus, the concept of occupational health and safety is created as an integrated system of "safety climate", which:

– takes into account the changes in the organization of work;

– envisages an impact assessment of all the potential risks on a person not only in the short term, but also in the long term;

– includes the requirement of a systematic preventive approach to the problem of occupational hazards.

Generally, the concept foresees the following areas:

– risk assessment;

– information provision to all management structures;

– development of cooperation in the field of occupational health and safety.

Those have successfully been implemented in Ukraine and are mirrored in the regulations.

However, the change in perceptions about occupational health and safety in the light of new conceptual approaches:

– necessitates assessment of the criteria that underlie the concept;

– formulates tasks for progress towards creating an integrated “safety climate” system. The unified technique is useful when designing software for HSEMS that is a component of a discrete structure of the program algorithm. In the future, we plan to use the proposed method in the system of compulsory social insurance.

6. Conclusions

As a result of the research:

1. The developed algorithm is the basis of mathematical modeling of the occupational health and safety management system. The algorithm includes the developed sequence of stages to determine the effectiveness of the HSE management system and identify the factors of injury, physiological and organizational reasons at an enterprise.

2. The unified methodology for OH monitoring is developed. The risk matrix was built. The matrix is based on the requirements collected from the normative and technical documentation. At the zero level of the matrix, there is a low-risk value (the range is 1–11). However, it is probably only theoretically possible result, which does not occur in real practice. Since all the parameters, included in the formula for determining R, have high values (the range is 33–80 and 81–200) on working conditions, health, age and seniority, according to recent studies [22–26]. The essence of the technique is in the fact that the dependences of the risk levels and indicators of hazardous and harmful production factors give the opportunity to determine the level of the OH and the effectiveness of the HSE management system, which includes:

– the proposed indicators of harmful and dangerous production factors;

– the proposed generalized coefficient of the state of occupational health and safety.

3. The developed technique:

– allows improving the process of monitoring of harmful and hazardous working conditions;

– serves the purposes of prevention, which is based on the existing threats and hazards in the workplace;

– differs from the existing ones in the fact that additional stages of assessment are proposed.

When implementing the technique, the social effect is 11 %.

The named components, in turn, allow improving the assessment of the working conditions at an enterprise and determining whether the HSE management system is functioning properly.

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