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Improvement of the approach to hazard identification and industrial risk management, taking into account the requirements of current legal and regulatory acts

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ABSTRACT

Purpose: Improving the systematic approach to planning and rationalizing labour protection measures at oil and gas enterprises, based on the results of hazard identification and industrial risk assessment. At the same time, the main task of the risk management process is to ensure the rights of employees guaranteed by the current legislation, namely, to create proper, safe and healthy working conditions.

Design/methodology/approach: A comparative legal method for identifying the features of European and Ukrainian legislation in the occupational safety and health field; a structural-logical method for determining the main directions for the further development of the occupational safety and health management system at enterprises; analysis and generalization of well-known scientific results on the research topic; statistical analysis to identify the relationship between the industrial risk' level and various factors that may affect its value; applied systems analysis and mathematical modelling method for new methodological approaches' development to assessing of hazards' likelihood and their consequences' severity were used. The basis for improving the systematic approach to planning and rationalizing labour protection measures is based on the standard IEC 61882:2001. The statistics are taken from the "Messages" information system, which operates in the State Service of Ukraine on Labour and is designed to collect and process data on occupational injuries.

Findings: An analysis of the current legislative and regulatory acts showed promising directions for their improvement. A mathematical model for scoring industrial risk is proposed, which takes into account the relationship between industrial risk and preventive measures and the time of their implementation. The calculation system developed on the basis of the proposed model provided a reduction in the time for processing data and calculating the values of industrial risks by 20...25%.

Research limitations/implications: Statistical data on industrial injuries at enterprises of the oil and gas industry of Ukraine for 2018-2019 were used.

Practical implications: Implementation of the proposed systematic approach to the organization of occupational safety and health management at enterprises has shown its simplicity and effectiveness, which can induce employers to finance reasonable and timely preventive measures.

Originality/value: The method has been improved by decreasing the discreteness step in the assessment of industrial risk components, which has increased its accuracy; by developing a mathematical model for calculating the probability of a hazard, taking into account the frequency with which workers are exposed to danger, which eliminates the need to involve experts for an expert assessment at this stage.

Keywords: Labour protection, Industrial risk, Hazard identification, Oil and gas industry, Mathematical modelling

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The occurrence of the accidents' majority in any industry, both in the present and in the past, can be traced to the absence or weak implementation of occupational safety and health management systems [1-4]. The International Labour Organization (ILO) report on workers' health and safety in 2015 argues that industries must do more to improve worker health and safety at work [5].

The oil and gas sector is one of many industries that expose workers to multiple hazards. This is due to the fact that in the production processes of the oil and gas industry, a wide range of works, equipment and mechanisms are used that belong to the category of increased danger. In addition, the main production workers in the oil and gas industry are exposed to crystalline silica at dangerous levels that exceed occupational health standards, and also work in conditions of high levels of particulate matter in the air of the working area, benzene, noise, radiation [6]. Leakage of hydrocarbons, falling objects, fires, explosions, hydrogen sulfide emissions, falls, electric shock, burns, etc. occur quite often. [7,8]. As shown in [9], workers in the oil and gas sector suffer from bruises, cuts and lacerations in the legs, arms, fingers and eyes. The level of industrial mortality in the oil and gas industry is 2.5 times higher than in the construction industry and 7 times higher than in the general industry [6].

Any unreasonable or risky actions of workers can potentially lead to accidents at work [10,11] and serious disasters, such as the Montara blowout in 2010 [12] and the explosion at the Texas City oil refinery in 2005 [13]. A significant number of industrial injuries are associated with organizational and technical reasons. Thus, in the late 1920s, researchers studied 75,000 industrial accidents and concluded that 88% of accidents were caused by the behaviour of risky workers [14]. In the case of proper safety planning, implementation of management procedures and production culture, accidents of any form can be prevented on the spot, since all events that occur are based on causal relationships [15].

Thus, starting from the first phase of operational activities, attention should be paid to the prevention of accidents. In this regard, compliance with the rules and regulations for the technical operation of equipment, technical systems, as well as the requirements of technological regulations for conducting processes is the key to maintaining the prescribed level of production safety.

To ensure effective prevention of occupational injuries, it is crucial to determine the probable causes of accidents, and justify the appropriate measures and protective equipment [16,17]. For clarity, the following definitions have been used: "Occupational injury is defined as any injury, illness or death resulting from an occupational accident; an occupational disease is a disease that is contracted as a result of exposure over a period of time to risk factors arising from work activities; an industrial accident is an unexpected and unplanned incident, including acts of violence related to work or in connection with it" [5].

At first glance, the scheme for preventing occupational injuries is obvious and is based on the study of the links between the risks (threats, dangers) of injury and measures to reduce the impact of risks to an acceptable level. This problem becomes especially urgent when it is necessary to calculate quantitative assessments and predict risk levels for planning labour protection measures aimed at preventing accidents at oil and gas enterprises.

However, the main problem in this matter is the imperfection of the legislative, regulatory, and normative-technical framework for regulating relations in the field of labour protection, as well as the imperfection of the centralized system of labour protection management, which differs from the subject-oriented European system of occupational safety management [18]. In the developed countries of the world, the industrial safety management system consists in organizing a model based on economic mechanisms. This means that financing of measures to prevent accidents and occupational diseases is more profitable for employers than compensation for damage to victims [19,20]. Thus, it is necessary to create conditions under which employers will be interested in financing preventive measures, reduce the likelihood of accidents, injuries and occupational diseases at enterprises. At the same time, the key element for improving the OSH management system of enterprises is the application of a risk-based approach.

Based on the foregoing, the work' purpose is improvement the systematic approach to planning and rationalizing labour protection measures at oil and gas enterprises, based on the results of hazard identification and industrial risk assessment. At the same time, the main task of the risk management process is to ensure the rights of employees guaranteed by the current legislation, namely, to create proper, safe and healthy working conditions.

2. Materials and methods

To study the requirements of legislative and legal norms in the occupational safety and health field, the following were used:

- a comparative legal method for identifying the features of European and Ukrainian legislation in the occupational safety and health field;
- a structural-logical method for determining the main directions for the further development of the occupational safety and health management system at enterprises.

To improve a systematic approach to planning and rationalizing labour protection measures at oil and gas enterprises, the following methods were used:

- analysis and generalization of well-known scientific results on the research topic;
- statistical analysis to identify the relationship between the industrial risk' level and various factors that may affect its value;
- applied systems analysis and mathematical modelling method for new methodological approaches' development to assessing of hazards' likelihood and their consequences' severity was applied.

The basis for improving the systematic approach to planning and rationalizing labour protection measures is based on the approach set out in the international standard IEC 61882:2001.

The research information base used for mathematical modelling consists of statistical materials on industrial injuries at enterprises of the oil and gas industry of Ukraine for 2018-2019. The statistics are taken from the "Messages" information system, which is implemented at the state level and is used by employees of the State Service of Ukraine on Labour. It is designed to collect and process data on occupational injuries. This system is a system for official use and cannot be made publicly available due to the presence of confidential information, the dissemination of which is prohibited by the legislation of Ukraine.

3. Results and discussion

3.1. Features of European and Ukrainian legislation in the field of occupational safety and health

In recent years, certification of the production management system, and especially occupational health and safety management, has become increasingly important in order to remain competitive. This is because the long-term success of an organization depends on its ability to improve its performance in the face of difficult environmental contingencies.

In developing countries, the implementation of an OSH management system usually faces various difficulties. For example, according to the Ukrainian legislation on labour protection [22], financing of labour protection measures is carried out from deductions, which amount to at least 0.5 percent of the wages fund for the previous year. However, due to the difficult economic situation of the country, it is classified as a country with lower-middle income economies [23], and therefore the funds allocated for labour protection are also not enough to ensure the maximum possible safety of workers. In addition, in order to avoid payment for accidents, the employer may hide the true rates of injury or illness of workers or avoid formal employment of workers [2]. Although enterprises are required to conclude a Collective Agreement, which is a legal act regulating labour and socio-economic relations between the employer and employees on the basis of mutual agreement of the parties in accordance with the document [24]. The situation is similar in other lower-middle-income and low-income countries [1,25].

Ukraine is a member of the European Union's Eastern Partnership program (since 2009). Building on ILO's call for labour inspection systems in accordance with ILO standards Article 427 in the control, supervisory and management functions of the State Service on Labour include mandatory certification of workplaces within the timeframes established by law [26]. The main purpose of certification is to regulate the relationship between the owner of the enterprise (his authorized manager) and employees in the exercise of their rights to healthy and safe working conditions, preferential pensions, benefits and compensation for work in unfavourable conditions, determined by the current legislation on labour protection. In addition, in Ukraine, social protection is provided for persons who have suffered from industrial accidents or who have received an occupational disease in accordance with the law [27]. This fact is undoubtedly positive in the development of the occupational safety and health management system in enterprises.

For the successful implementation of European experience in the further development of the occupational safety and health management system in enterprises, it is necessary to comply with the standards introduced by the International Organization for Standardization (ISO), namely the standards of the OHSAS 18000 series, since these standards can be applied in organizations of all types, regardless of their form property and production volumes [21]. The OHSAS 18001 standard is built on the principle of risk management in the workplace in accordance with the general model of preventive and preventive measures specified in Directive No. 89/391/EEC [28]. Consequently, the risk-based approach is defined as a methodological basis for building safety and health management systems at Ukrainian enterprises. But the application of the OHSAS 18001 standard is complicated by the fact that the requirements of this standard are directive in nature, and specific ways of implementing its provisions are not defined.

The basic document, in which the recommendations of the methodology for the external assessment of risks are є the DSTU standard IEC/ISO 31010:2013 "Risk Management. Methodology of the overall risk assessment" [29]. It should be noted that the initial stage of risk assessment is the identification of production factors that cause the negative impact of hazards on workers. The analysis of the standards shows that the identification of hazards includes determining the causes, sources of risk (danger in the context of physical harm), events, situations or circumstances that may have a material impact on the achievement of goals, as well as determining the nature of this impact [29].

Among a significant list of risk assessment methods, based on the recommendations of the standard, two of them HAZOP and HAZID were identified. In terms of functional characteristics, the HAZOP method (IEC 61882: 2001) ensures the achievement of safe factors and operability with medium resources and capabilities, as well as with a high degree of uncertainty of the influence of factors and the complexity of their identification, which is typical for oil and gas industry enterprises. It is known that in developing countries, including Ukraine, enterprises have very limited opportunities due to low funding. However, this method does not provide quantitative outputs. Although this method does not allow predicting the risk, at the same time it is preferable for detailed and structured identification of hazards for individual technological systems (sections, nodes) at the final stage when the main design, technological and organizational solutions have been worked out. At the initial stages of design, in order to select design solutions (protective measures) that ensure risk reduction, the HAZID method (ISO 17776-2016) is effective to identify all significant hazards associated with the activity in question. Since Ukraine does not legally define specific ways of implementing an occupational safety and health management system at enterprises, enterprises independently choose risk management methods and HAZID is most widespread in Ukraine since it is focused on the oil and gas industry and is available for use.

In Ukraine, in the oil and gas industry, the standard SOU 60.330019801-081:2010 "Industrial safety management system. Hazard identification and risk assessment. Methodology", which is based on the method HAZID. The use of this methodology makes it possible to determine potential hazards at the workplaces of oil and gas enterprises and to assess possible risks. Its advantage is the ability to identify industrial risks both for individual facilities and for the enterprise as a whole. In addition, the application of this technique makes it possible to develop measures for the safe operation of facilities even at the design stage, taking into account the available statistical data on the occurrence of hazardous situations. However, a significant drawback is a simplified approach to the choice of score scales, according to which the factors that determine the occupational risk are assessed (the likelihood of a hazard, the frequency with which workers are exposed to danger; the severity of the consequences of the hazard). A simplified approach is that the scales for determining the estimates of the components of occupational risk have significant discreteness, which prevents an increase in the accuracy of their assessment. Other disadvantages include insufficient certainty of the hazard identification procedure and an insufficiently substantiated approach to planning measures to reduce industrial risk.

Today, quantitative methods for assessing industrial (professional) risk are widely used for practical application [30-32]. Among them, given its simplicity and clarity, the matrix method "probability-damage" remains the most widespread. BS 8800:2004 [33] describes this method as a basic method for assessing risks in terms of their likelihood and severity of consequences. Moreover, its relevance is confirmed by the European experience in risk assessment [34]. For a quantitative assessment of the possibility of a hazard and the severity of the consequences, the corresponding score scales are most often used. After the matrix is formed and calculations are made, ranking is carried out according to the calculated value of risks. The basic method has a significant number of modifications of scales and the number of multipliers [18,35], although it does not have the ability to universalize the matrix for use in enterprises of various industries and provides the complexity of the selection of assessment scales. In addition, this method has a sufficiently high degree of subjectivity of assessments, and as a consequence, insufficient scientific validity of the results. Therefore, it can be assumed that increasing the accuracy of risk assessment can be achieved by using several methods of risk assessment, applying them at different stages of this process. However, it is important to create a methodology that can be used by workers without special education and work experience, since these are expensive and time-consuming procedures.

3.2. Features of identification of hazard factors

According to the characteristics of the identification of factors, they can be conditionally divided into two groups: factors that are subject to instrumental measurement (objective identification) and factors that are not subject to instrumental measurement.

The factors of the first group include the level of noise, vibration, microclimatic parameters of the production environment, and others. Determination of the class of working conditions by production factors at workplaces, as well as the principles of rationing the maximum permissible levels of these factors, instruments and methods for their measurement are given in the relevant documents [36-38]. The second group includes, in particular, psychophysiological factors, as well as individual production factors, the impact of which on a person cannot be quantified.

Since today in the field of labour protection and industrial safety there are no risk assessment criteria defined by regulatory documents, it is recommended to divide the risk levels into three ranges [29]:

- Upper range – an unacceptable level of risk (the risk that is in this range must be minimized despite the necessary resources);
- Medium range – an acceptable level (the benefits and benefits from activities under risk conditions are balanced with potential negative consequences);
- The lower range – an insignificant level of risk (the activities of the enterprise can be carried out without additional measures to minimize risks).

It is this approach to risk assessment that has found application in scientific works [18,39]. In this case, the hazard identification procedure should be carried out by the employer or an involved expert (group) [28].

The result of risk management should be a decrease in the level of hazardous and harmful factors present in the workplace to an acceptable value. It should be noted that preventive measures, the implementation of which is regulated by legislative or other binding documents, are carried out regardless of the results of the risk assessment.

3.3. Improving of the approach to hazard identification and industrial risk management at oil and gas enterprises

The improvement of the approach to hazard identification and industrial risk management is based on the combined use of two methods: HAZOP and HAZID, since methods based on probability theory, matrices, expert assessments, etc. need specially trained specialists, which is a difficult task in countries with underdeveloped economies. The HAZOP method allows you to identify hazards for personnel, equipment, and the environment. In addition to identifying hazards and ranking them, the method allows us to identify ambiguities and inaccuracies in safety instructions and contributes to their further improvement. As a result of using the HAZOP method, it is provided:

- Systematic research of dangerous situations;
- Data processing and calculation of industrial risk values;
- Study of the causes and consequences of errors of performers.

At the same time, the use of the HAZOP method has the following disadvantages:

- Duration in time;
- Requires detailed information about the state of objects and processes;
- The analysis is focused on individual details, and the study of problems in general is difficult;
- The method is limited by the purpose and objectives of the study defined for the group of experts;
- The method is mainly based on expert assessments and does not use the capabilities of such methods as statistical analysis and mathematical modelling insufficiently.

Taking into account such disadvantages, it is proposed to additionally use the HAZID method, which is, first of all, a tool for identifying hazards. Implementation of HAZID aims to ensure the selection of the most efficient and economically viable option for the action plan. The main advantages of HAZID are:

- Identification of specific hazards at the stage of preliminary data analysis;
- The possibility of developing a register of typical hazards for their further in-depth analysis;
- The possibility of analysing the consequences of the implementation of hazards at the early stages of the development of the action plan;
- The ability to identify the main characteristics of existing hazards (first of all, the likelihood of their occurrence and the severity of the consequences) in order to assess industrial risks at the stage of forming the options for the action plan.

Taking into account the peculiarities of the technical operation of equipment and technical systems at the enterprises of the oil and gas industry, an industrial risk assessment is carried out on the basis of a score scale:

$$R = P \cdot E \cdot S \tag{1}$$

where R is the scoring of industrial risk; P – score assessment of the danger' probability; E – frequency' score assessment with which workers are exposed to danger; S – severity' score assessment of the consequences from the implementation of the hazard.

Since all the components of formula (1) have significant discreteness, in order to obtain a reliable assessment of industrial risk, this study' authors propose to use a score assessment for each component with a discreteness of 0.5. This approach will improve the accuracy of the each component' risk assessment and of the risk' value for the enterprise as a whole.

In the presence of statistical data on incidents of accidents, occupational diseases, etc. to assess the likelihood of hazard P (in scores), a trend-factor model should be built of the form:

$$P = f_1(t) + f_2(X) + f_3(Z) \tag{2}$$

where $f_1(t)$ – the trend component that takes into account the influence of time on the P score; $f_2(X)$ – the component that assesses the influence of production factors (including organizational, technical and psycho-physiological); $f_3(Z)$ – the component that assesses the impact of measures on improving production safety in previous periods of time.

In this case, the score for the likelihood of a hazard varies from 0 to 10 (Tab. 1).

As practical experience has shown, the first and the second component in expression (2) reflects changes in the score associated with equipment depreciation, seasonal changes and etc. The third component of expression (2) takes into account the changes in industrial risk depending on the protective measures taken, therefore, in improving the risk management method, efforts are focused on this component.

Using statistical data on injuries and diseases at certain workplaces, in workshops and departments of Ukrainian oil and gas enterprises, as well as expert estimates, Table 2 was developed to determine the value of E, that is frequency' score assessment with which workers are exposed of danger. Further, the E value (column 1 of Table 2) and the value of x (column 4 of Table 2) were taken as the initial data, and the dependence was obtained by the method of least squares:

$$E = 6.641 - 0.988 \cdot x + 0.048 \cdot x^2 - 0.00056 \cdot x^3 + 1.73 \cdot 10^{-6} \cdot x^4 \tag{3}$$

where x – the duration of safe work at the workplace, days.

The duration of safe work at the workplace means that during a certain period of time not a single event has occurred that predetermines the production risk, that is, the state of working conditions under which the impact on workers of hazardous and harmful production factors is eliminated or this impact does not exceed the maximum valid values. The correlation coefficient of the resulting model is 0.987, which indicates a high accuracy of the approximation. Figure 1 shows the calculated (Curve 1) and predicted (Curve 2) values of the scoring of the frequency with which workers are exposed to danger.

Table 1.
Score P of the probability of the danger' implementation

Scores	Probability		Periodicity of the danger' implementation
10	Very high	> 0.1	During the shift
6-9	High	0.01-0.1	During the week
3-5	Average	0.001-0.01	Within a month
1-2	Small	0.0001-0.001	During the year
0.5	Very small	0.00001-0.0001	During the service life

Table 2.
Estimation of the frequency E with which workers are exposed to danger (in scores)

Scores	Characteristic	Frequency of work in the danger zone	Duration of safe work at the workplace, days
9-10	Constantly	During the change constantly	0.2
7-8	Regular	Once per shift	1
5-6	Periodically	Once a week	5
3-4	Sometimes	Once a month	20
1-2	Rarely	Several times a year	100
0.5	hardly ever	Once a year	200

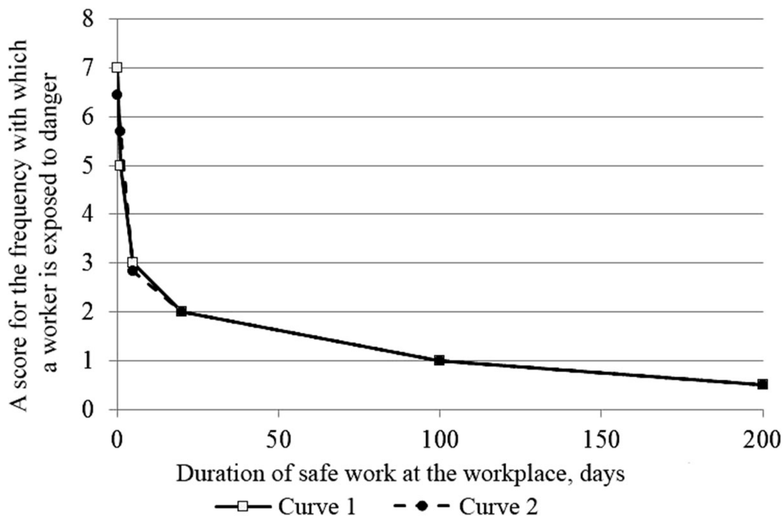


Fig. 1. Estimated and predicted values of the frequency' score with which workers are exposed to danger

Taking into account the high accuracy of approximation, dependence (3) makes it possible to quickly determine the duration of safe work at the workplace (in days) by calculation, that is, the need to involve experts for expert assessment is excluded. This means that the assessment can be carried out by employees who do not have special education and experience in expert assessment, which significantly contributes to a more efficient and faster implementation of the occupational safety and health management system and risk management.

For the scoring of the severity of the consequences of hazard S, it is proposed to use a more accurate assessment by joint use of expert estimates and statistics of economic assessment of the consequences of hazardous situations. Based on the statistical data of the oil and gas industry' enterprises of Ukraine on the consequences of dangerous situations, a trend-factor model is proposed:

$$S = f_4(t) + f_5(X) + f_6(Z) \quad (4)$$

where $f_4(t)$ – the trend component that takes into account the influence of time t on the score S; $f_5(X)$ – the component that assesses the influence of factors that affect the industrial risk (including organizational, technical and psychophysiological); $f_6(Z)$ – the component that assesses the measures' impact on improving production safety in previous periods of time.

Table 3.
Score of the consequences' severity S

Scores	Category of consequences	Life and health of people	Material damage, thousand UAH (at the time of the study 1 UAH = 27.5 USD)
60	Catastrophe	A large number of human victims	above 50,000
40-59	Major accident	Group accident (more than 1 death)	15,000-50,000
15-39	Very significant	One death	1,500-15,000
7-14	Significant	Disability, permanent disability	1,500-50
3-6	Serious	Temporary or partial disability	5-50
1-2	Insignificant	Minor injuries, first aid	less than 5

Table 4.
Scoring the probability of the danger' implementation, taking into account the frequency with which workers are exposed to hazard P_E

Scores	Characteristic	Frequency of work in the danger zone	Duration of safe work at the workplace, days
65-100	Constantly	During the shift, constantly	0.2
37-64	Regularly	Once per shift	1
17-36	Periodically	Once a week	5
4-16	Sometimes	Once a month	20
2-3	Seldom	Several times a year	100
0-1	Rarely	Once a year	200

Table 5.
Assessment of industrial risks and recommended actions

Risk assessment		Category	Recommended actions
in scores	quality		
over 400	very big	unacceptable	Work must not be started or continued until the risk has been reduced to an acceptable level.
200-399	big		Work cannot be started. If the work has started and cannot be stopped, it is necessary to take measures to reduce the risk within three months
70-199	middle	permissible	Take measures to reduce the risk within the time frame specified in the PD
20-69	low		Observe the preventive measures applied, ensure control
less than 19	minor		No need to take any measures

In this model, the first term reflects changes in the score associated with financial and economic changes in the country (inflation, changes in the regulatory framework, etc.). Since the company cannot influence this component, then in risk management efforts should be focused on the second and third components. Analysing the specific data of enterprises on the severity of the consequences S of undesirable events, Table 3 presents the result of the estimates in score.

Simplification of the formula for calculating the scoring of industrial risk can be achieved by combining the indicators P and E into one indicator, which is determined as the result of the product of the expert scoring of the indicator P and the mathematical model of the indicator E. This means that the scoring estimate of the probability of a hazard, taking into account the frequency which workers are at risk is defined by the expression:

$$P_E = P \cdot E = P \cdot (6.641\text{-}0.988 \cdot x + 0.048 \cdot x^2 - 0.00056 \cdot x^3 + 1.73 \cdot 10^{-6} \cdot x^4) \quad (5)$$

Using relationship (5) and Table 2, Table 4 presents a score for the danger' probability, taking into account the frequency with which workers are exposed to hazard, ranging from 0 to 100.

Then equation (1) will have the form:

$$R = P_E \cdot S, \quad (6)$$

where R – point score of industrial risk; P_E – scoring the danger' probability, taking into account the frequency with which workers are exposed to danger; S – score assessment of the consequences' severity from danger.

Thus, taking into account the data in Table 5, the value of the industrial risk score (R) can be obtained and a decision made on the need to develop and implement measures to reduce risk.

The uses of the proposed approach to industrial risk determine reduces the amount of work to identifying hazards and eliminates some of the errors of experts associated with the human factor. In addition, the proposed scoring scales increase the results' accuracy obtained, and, consequently, the efficiency of planning labour protection measures in production.

3.4. Development of a mathematical model for assessing measures to reduce industrial risks

To justify the choice of a management decision, it is necessary to develop a criterion that will guide the person making the decision. For scientific support of management decisions, it is necessary to use predictive assessments of the development of the situation (that is, predictive assessments of industrial risks), taking into account the expected results of the implementation of labour protection measures. These predictive estimates can be obtained using an appropriate mathematical model. It is important to remember that there is a minimum possible risk' value, which cannot be reduced by implementing measures.

According to the methodology for identifying hazards and analysing risks (proposed above), at the first stage, the initial data arrays are formed for each facility of the enterprise in the form of a table, which indicates the assessment' date, the measures' content, the risk score before and after the measures' implementation.

In a formalized form, the relationship between industrial risk and preventive measures can be presented in the form:

$$R = \sum_{j=1}^{m} R_j + \sum_{i=1}^{n} f_i\,(z_i), \qquad (7)$$

where R_j– industrial risk of the j-th hazardous situation; $f_i(z_i)$ – function of the influence of the i-th event (z_i) on industrial risk.

In expression (7), the values of R_m correspond to the industrial risk' scores for the measures' implementation.

The function of the influence of i-th preventive measure on industrial risk is based on the difference in the scores of the industrial risk before and after the implementation of the measures.

To separate the impact of hazards and measures to reduce production risks and thereby simplify calculations for a separate preventive measure, dependence (7) can be transformed in two ways:

- To determine the impact of the event on industrial risk:

  $$R = R_0 + f_i\,(Z_i), \qquad (8)$$

  where R_0 – industrial risk before the implementation of the i-th preventive measure; $f_i(Z_i)$ – function of the influence of the i-th preventive measure on the risk of a dangerous situation.
- To determine the impact of a specific occupational hazard on occupational risk:

  $$R = R_j + f_i\,(Z_i), \qquad (9)$$

  where R_j – industrial risk from the j-th occupational hazard to the implementation of the i-th preventive measure.

To construct mathematical models for predicting the values of industrial risk as a result of the implementation of preventive measures, the following matrices should be defined: A_1 – the matrix for accounting for uncontrolled changes in industrial risk and A_2 – the matrix of coefficients of the measures' influence on industrial risk [40]. Then the mathematical model of the forecast will have the form

$$\begin{cases} R(t+1) = R(t) + A_1 \cdot R(0) + A_2 \cdot Z(t) \\ t = 0, \ldots, N-1 \\ R(0) = r \\ R(t) \geq 0 \\ Z(t) \geq 0 \end{cases} \qquad (10)$$

where N – number of forecast points; r – the initial risk' value; Z(t) – the preventive measures' impact on occupational risk.

Writing down expression (10) in differential form, we obtain a mathematical model of the change in occupational risk, taking into account the influence of preventive measures

$$\begin{cases} \dfrac{dR}{dt} = A_1 \cdot R(0) + A_2 \cdot Z(t, t_0) \\ t = 0, \ldots, N-1 \\ R(0) = r \\ R(t) \geq 0 \\ Z(t) \geq 0 \end{cases} \qquad (11)$$

Next, we write the matrix A_1 in the form (Tab. 6):

Table 6.
The coefficients' matrix of the hazards' influence on the change in industrial risk

Dangerous situation	Time t				
	1	2	…	T-1	T
1	a_{11}	a_{12}	…	a_{1T-1}	a_{1T}
…	…	…	…	…	…
n	a_{n1}	a_{n2}	…	a_{nT-1}	a_{nT}

The coefficients a_{ij} of the matrix A_1 are determined on the basis of statistical data or on the basis of expert estimates. According to Table 6, mathematical models of coefficients of hazards' influence on the change in industrial risk are built. Since the constructed models do not exceed the third order, then, according to the results of the study of statistical modelling methods, it was found that it is enough to construct a regression polynomial model of the third order:

$$A_{1_i} = b_{i0} + b_{i1} \cdot t + b_{i2} \cdot t^2 + b_{i3} \cdot t^3, \tag{12}$$

where b_{i0}, b_{i1}, b_{i2}, b_{i3} – regression coefficients of the hazards' impact model on the change in industrial risk for the i-th hazard.

According to (12), the component of model (11), which determines the scoring of the hazards' impact on the change in industrial risk, can be represented as:

$$A_1 \cdot R(0) = \sum_{i=1}^{n} A_{1_i} \cdot R(0) = \sum_{i=1}^{n} (b_{i0} + b_{i1} \cdot t + b_{i2} \cdot t^2 + b_{i3} \cdot t^3) \cdot r. \tag{13}$$

Further, on the basis of the statistical data of a particular enterprise or other enterprises of the oil and gas industry, the coefficients of d_{ij} of the matrix A_2 are determined. In the absence of statistical data, expert assessments are used, which are made by a group of experts when identifying hazards at the facilities of the enterprise.

It is proposed to represent the matrix A_2 in the form (Tab. 7).

Table 7.
Coefficients' matrix of measures influence on change in industrial risk

Measures	Time of measure' impact on industrial risk Δt				
	1	2	…	T-1	T
Measure 1	d_{11}	d_{12}	…	d_{1T-1}	d_{1T}
…	…	…	…	…	…
Measure m	d_{m1}	d_{m2}	…	d_{mT-1}	d_{mT}

According to Table 7, mathematical models of coefficients of measures' influence on the change in industrial risk are built. As in the previous case, in this case it is also sufficient to construct a regression polynomial model of the third order:

$$A_{1_2} = k_{i0} + k_{i1} \cdot t + k_{i2} \cdot t^2 + k_{i3} \cdot t^3, \tag{14}$$

where k_{i0}, k_{i1}, k_{i2}, k_{i3} – regression coefficients of the measures' impact model on the change in industrial risk for the i-th measure.

According to (14), the model' component (11), which determines the measures' impact on the change in the risk of hazardous situations can be represented as:

$$A_2 \cdot \Delta R = \sum_{i=1}^{n} (k_{i0} + k_{i1} \cdot (t - t_{0_i}) + k_{i2} \cdot (t - t_{0_i})^2 + k_{i3} \cdot (t - t_{0_i})^3) \cdot \Delta R_i \tag{15}$$

where ΔR – change in the industrial risk' value due to the implementation of the i-th measure at the time of its implementation; t_{0_i} – the implementation time of the i-th event, n – the number of events.

If in the forecast period it is possible to implement one measure several times, the function of taking into account the time of implementation of i-th measure is determined and expression (15) will look like:

$$A_2 \cdot \Delta R = \sum_{j=1}^{m} (k_{j0} + k_{j1} \cdot (t - f_j(t)) + k_{j2} \cdot (t - f_j(t))^2 + k_{j3} \cdot (t - f_j(t))^3) \cdot \Delta R_j \tag{16}$$

where $f_j(t)$ – function of accounting for the implementation time of the j-th measure.

The function of accounting for the implementation time of the j-th measure determines the moments of maximum impact on the value of the industrial risk score, its implementation and the number of such protective measures. As an example, for a better understanding of function (16), Figure 2 shows a graph of the function of taking into account the time of implementation of three measures during the planning period of 12 months. To build a graph (Fig. 2), it was conventionally accepted that the measure should be implemented in January, May and September.

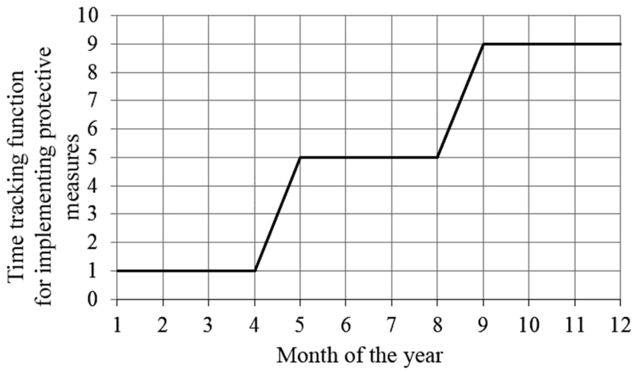


Fig. 2. Function that takes into account the time factor for the implementation of protective measures

Figure 3 demonstrates the change in the risk score depending on the time of protective measure implementation, which is described by function (16). As can be seen from Figure 3, with the implementation of one measure, the industrial risk' value is reduced by 400 points in the 1st month (that is, at the time of the implementation of the event) by 0 points in the 12th month (if this measure is no longer implemented this year). When this measure is implemented three times a year (that is, in the 1st, 5th and 9th months), the industrial risk' value will decrease by 385...400 points.

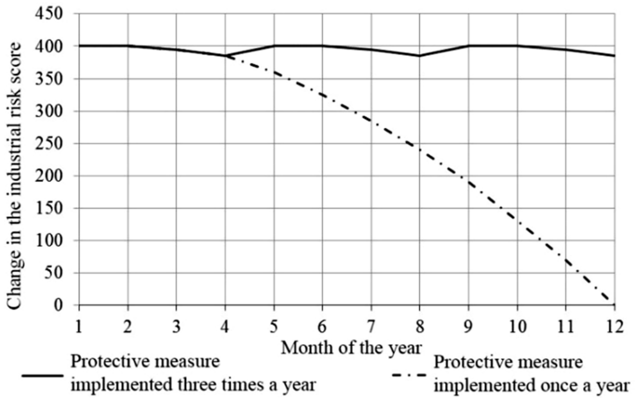


Fig. 3. The impact of the protective measure on the score assessment of industrial risk

Substituting expressions (13) and (16) in (11), the expression takes the form (17). Integrating (17), we obtain an expression for determining the scoring of industrial risk taking into account the measures' impact (18).

$$\frac{dR}{dt} = \sum_{i=1}^{n}(b_{i_0} + b_{i_1} \cdot t + b_{i_2} \cdot t^2 + b_{i_3} \cdot t^3) \cdot r + \\ + \sum_{j=1}^{m}(k_{j_0} + k_{j_1} \cdot (t - f_j(t)) + \\ + k_{j_2} \cdot (t - f_j(t))^2 + k_{j_3} \cdot (t - f_j(t))^3) \cdot \Delta R_j \quad (17)$$

where b_{i0}, b_{i1}, b_{i2}, b_{i3} – regression coefficients of the hazards' impact model on the change in industrial risk for the i-th hazard; k_{i0}, k_{i1}, k_{i2}, k_{i3} – regression coefficients of the measures' impact model on the change in industrial risk for the i-th measure; r – initial risk value; ΔR_i – change in the industrial risk' value due to the implementation of the i-th measure at the time of its implementation; $f_j(t)$ – function of accounting for the implementation time of the j-th measure.

$$R(t) = \sum_{i=1}^{n}(b_{i_0} \cdot t + 0.5 \cdot b_{i_1} \cdot t^2 + \frac{b_{i_2} \cdot t^3}{3} + \frac{b_{i_3} \cdot t^4}{4}) \cdot r + \\ + \sum_{j=1}^{m}(k_{j_0} \cdot t + 0.5 \cdot k_{j_1} \cdot (t - f_j(t))^2 + \\ + \frac{k_{j_2} \cdot (t - f_j(t))^3}{3} + \frac{k_{j_3} \cdot (t - f_j(t))^4}{4}) \cdot \Delta R_j \quad (18)$$

Expression (18) makes it possible to obtain the predicted value of the industrial risk at production facility in the considered time period t and proceed to assessing the effectiveness of the proposed plan for the implementation of protective measures. That is, the use of expression (18) allows, by evaluating the plan' effectiveness for the protective measures' implementation, to choose the most effective plan from the set of potential plans proposed by the expert group.

Thus, in the existing approaches to assessing industrial risks, the issues of the impact of preventive measures and consequences' predicting of these measures' implementation were not considered. The approach proposed in this study addresses this gap.

3.5. Implementation of research results

Taking into account the interest in reducing staff turnover, reducing the amount of payments for compensation and fines, as well as improving the quality of products, managers of many enterprises strive to create working conditions that meet the requirements of the current legislative and regulatory documents.

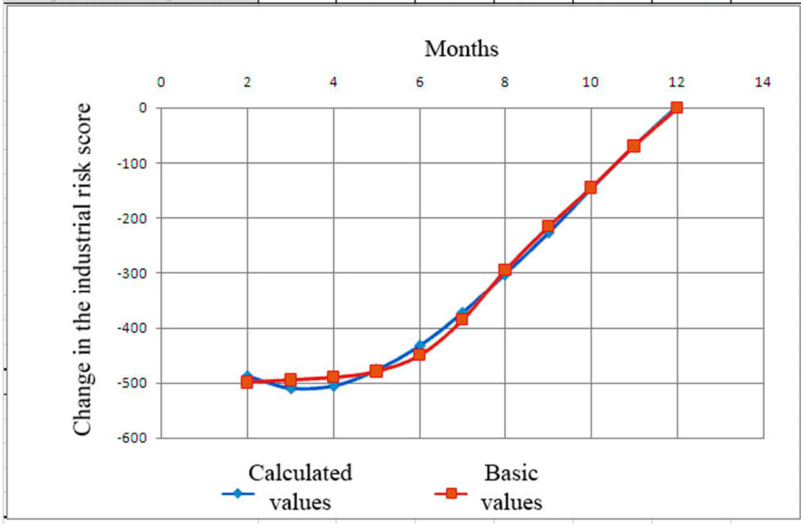
For the proposed model, the calculation system "Analysis of industrial risks" has been created, which is implemented in the "Microsoft Excel" environment. The choice of the "Microsoft Excel" environment is due to the wide distribution and availability of the software product without additional financial investments, great popularity among users due to use ease, and therefore this is the most optimal option at the system' implementation initial stage (trial period) until it receives good recommendations. This system is designed to provide information and analytical support for the preparation of preventive measures to reduce industrial risk. System functionality:

- Calculation of the score of the probability of change in production risk;
- Calculation of the point assessment of changes in industrial risk caused by the dangerous situations occurrence in the work process;
- Calculation of the point assessment of the measures impact on the industrial risk value;
- Calculation of the measures impact on industrial risk, taking into account the time of their implementation.

An example of the system' operation implemented at the enterprise JSC "Ukrgasvydobuvannya" (Ukraine) is shown in Figure 4.

Figure 5 shows an example of an analysis of the expected impact of the implementation of a labour protection measure on a change in the score for industrial risk. It should be emphasized that the use of the developed system has reduced the time for data processing and calculation of production risk values by 20...25%.

Date	1	2	3	4	5	6	7	8	9	10	11	12
Point score of industrial risk	2800	2300	2305	2310	2320	2350	2415	2505	2585	2655	2730	2800
Risk increase	0	-500	-495	-490	-480	-450	-385	-295	-215	-145	-70	0
Predictable risk reduction	0	-487.59	-509.23	-504.58	-477.60	-432.27	-372.55	-302.41	-225.82	-146.75	-69.16	2.97
Coefficients of the matrix A2	0	-0.975	-1.018	-1.009	-0.955	-0.865	-0.745	-0.605	-0.452	-0.293	-0.138	0.0059



Model	A0	A1	A2	A3
	-349.545	-104.575	19.09965	-0.66142

Correlation coefficient of the model 0.998222

Fig. 4. An example of the system operation based on the proposed model

Name of protective measure	Time t											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
$f(t_{01})$ – 1 measure	0	2	2	2	2	2	2	2	2	2	2	2
Predictable risk reduction	0	-487	-509	-504	-477	-432	-372	-302	-225	-146	-69	-2
$f(t_{01})$ – 2 measures	0	2	2	2	2	2	7	7	7	7	7	7
Predictable risk reduction	0	-487	-509	-504	-477	-432	-372	-487	-509	-504	-477	-432

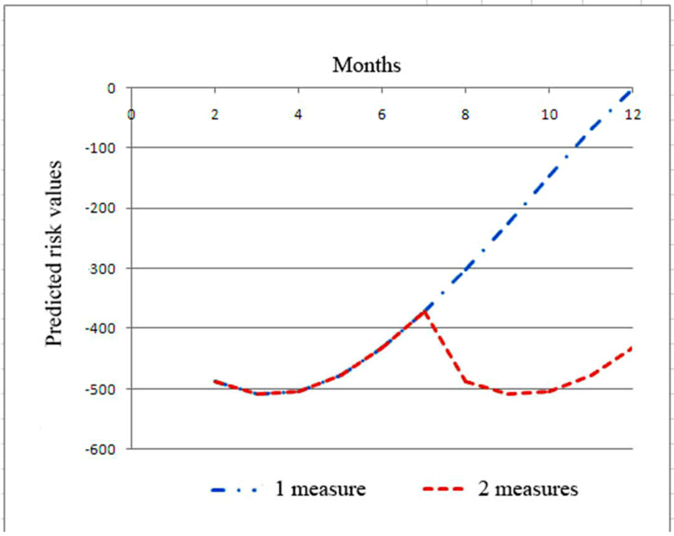


Fig. 5. The result of the implementation of the system in the existing production

4. Conclusions

Based on the results obtained, the following conclusions can be formulated:

1. An analysis of the current legislative and regulatory acts showed promising directions for their improvement, namely:
   - The need to introduce a risk-based approach, that is, to bring the requirements of the current Ukrainian acts closer to the European requirements;
   - For the development of an occupational safety and health management system at enterprises, it is necessary to comply with the standards introduced by the International Organization for Standardization (ISO), namely the standards of the OHSAS 18000 series, since these standards can be applied in organizations of all types, regardless of their form of ownership and production volumes;
   - To improve the accuracy of the industrial risk assessment, reduce the discreteness of its components, that is, the point scale of each component should be taken with a discreteness of 0.5.
2. Analysis of statistical data obtained at operating enterprises made it possible to make an assumption about the existence of a relationship between the level of production risk and the time of implementation of measures aimed at reducing it.
3. A mathematical model for scoring industrial risk is proposed, which takes into account the relationship between industrial risk and preventive measures and the time of their implementation. Application of the proposed mathematical model makes it possible to calculate the probability of a hazard, taking into account the frequency with which workers are exposed to danger.
4. The calculation system "Analysis of industrial risks" developed on the basis of the proposed model, when implemented at an operating enterprise, provided a reduction in the time for processing data and calculating the values of industrial risks by 20...25%.
5. Implementation of the proposed systematic approach to the organization of occupational safety and health management at enterprises has shown its simplicity and effectiveness, which can induce employers to finance reasonable and timely preventive measures.

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Additional information

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References

[1] A. Mekkathil, A. El-Menyar, H. Al-Thani, Occupational injuries in workers from different ethnicities, International Journal of Critical Illness and Injury Science 6/1 (2016) 25-32. DOI: https://doi.org/10.4103/2229-5151.177365

[2] O. Kruzhilko, V. Maystrenko, V. Kalinchyk, Y. Polukarov, L. Mitiuk, N. Bilotserkivska, L. Borysova, T. Kachur, Development of the effective information and analytical support of the OSH management system, Journal of Achievements in Materials and Manufacturing Engineering 99/2 (2020) 72-84. DOI: https://doi.org/10.5604/01.3001.0014.1777

[3] D. Sokolov, V. Sobyna, S. Vambol, V. Vambol, Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading. Archives of Materials Science and Engineering 94/2 (2018) 49-54. DOI: https://doi.org/10.5604/01.3001.0012.8658

[4] S. Ragimov, V. Sobyna, S. Vambol, V. Vambol, A. Feshchenko, A. Zakora, E. Strejekurov, V. Shalomov, Physical modelling of changes in the energy impact on a worker taking into account high-temperature radiation, Journal of Achievements in Materials and Manufacturing Engineering 91/1 (2018) 27-33. DOI: https://doi.org/10.5604/01.3001.0012.9654

[5] International Labour Organization, Safety and health at work: a vision for sustainable prevention, Proceedings of the XX World Congress on Safety and Health at Work 2014, Global Forum for Prevention, Frankfurt, 2014. Available from: https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_301214.pdf

[6] R.Z. Witter, L. Tenney, S. Clark, L.S. Newman, Occupational exposures in the oil and gas extraction industry: State of the science and research recommendations, American Journal of Industrial Medicine 57/7 (2014) 847-856. DOI: https://doi.org/10.1002/ajim.22316

[7] I. Sutton, Offshore Safety Management, William Andrew Publishing, Oxford, 2012. DOI: https://doi.org/10.1016/B978-1-4377-3524-6.00001-0

[8] Ministry of Health/Ghana Health Services, A hand book of occupational Health, GHS/MOH, Occupational and Environmental Health Unit, Accra, Ghana, 2012.

[9] S. Oppong, Common health, safety and environmental concerns in upstream oil and gas sector: Implications for HSE management in Ghana, Academicus International Scientific Journal 9 (2014) 93-106.

[10] N. Mozaffari, N. Mozaffari, S.M. Elahi, S. Vambol, V. Vambol, N.A. Khan, N. Khan, Kinetics study of CO molecules adsorption on Al_2O_3/Zeolite composite films prepared by roll-coating method, Surface Engineering (2020) 1-10. DOI: https://doi.org/10.1080/02670844.2020.1768628

[11] O. Kruzhilko, O. Polukarov, S. Vambol, V. Vambol, N.A. Khan, V. Maystrenko, V.P. Kalinchyk, A.H. Khan, Control of the workplace environment by physical factors and SMART monitoring. Archives of Materials Science and Engineering 103/1 (2020) 18-29. DOI: https://doi.org/10.5604/01.3001.0014.1770

[12] J. Hayes, Operator competence and capacity – Lessons from the Montara blowout, Safety Science 50/3 (2012) 563-574. DOI: https://doi.org/10.1016/j.ssci.2011.10.009

[13] A. Hopkins, Failure to learn: the BP Texas City refinery disaster, CCH Australia Limited, 2008.

[14] H.W. Heinrich, D. Petersen, N. Roos, Industrial Accident Prevention, McGraw Hill, New York, 1980.

[15] S.S. Hosseinian, Z.J. Torghabeh, Major theories of construction accident causation models: A literature review, International Journal of Advances in Engineering and Technology 4/2 (2012) 53-66.

[16] O.Y. Kashuba, N.B. Levkyn, E.A. Spyrydonov, M.S. Kovchuzhnyy, Analyz prychyn travmatyzma na shakhtakh Ukrayny, Visnyk Natsional′noho Tekhnichnoho Universytetu Ukrayiny "Kyyivs′kyy Politekhnichnyy Instytut". Seriya "Hirnytstvo 17 (2008) 172-177 (in Ukrainian).

[17] I.M. Podobyed, Vyyavlennya potentsiynykh nebezpek, yak skladova znyzhennya vyrobnychoho travmatyzmu ta profesiynykh zakhvoryuvan′ v APK. Problemy Okhorony Pratsi v Ukrayini.–K.: NNDIOP (2006) 17-24 (in Ukrainian).

[18] O.V. Bohdanova, Udoskonalennya naukovo-metodychnykh pidkhodiv do planuvannya zakhodiv zi znyzhennya vyrobnychykh ryzykiv: dys. … kand. tekhn. nauk. 05.26.01. Kyyiv, 2017. 164.

[19] O.A. Marinina, M.A. Nevskaya, Specific nature of labour management in the oil and gas sector in the Russian Far North, International Journal of Applied Business and Economic Research 15/8 (2017) 177-185.

[20] O.J. Blanchard, F. Jaumotte, P. Loungani, Labor market policies and IMF advice in advanced economies during the Great Recession, IZA Journal of Labor Policy 3/1 (2014) 2. https://doi.org/10.1186/2193-9004-3-2

[21] M.N. Vinodkumar, M. Bhasi, A study on the impact of management system certification on safety management, Safety Science 49/3 (2011) 498-507. DOI: https://doi.org/10.1016/j.ssci.2010.11.009

[22] Pro okhoronu pratsi: Zakon Ukrayiny vid 14.10.1992 r. № 2694-XII. Vidomosti Verkhovnoyi Rady Ukrayiny, № 49, 1992, St. 668. Available from: https://zakon.rada.gov.ua/laws/show/2694-12#Text

[23] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

[24] Pro kolektyvni dohovory i uhody: Zakon Ukrayiny vid 01.07.93 r. № 3357-XII. Vidomosti Verkhovnoyi Rady Ukrayiny, № 36, 1993, St.361. Available from: https://zakon.rada.gov.ua/laws/show/3356-12#Text

[25] S. Liu, E.N.K. Nkrumah, L.S. Akoto, E. Gyabeng, E. Nkrumah, The state of Occupational Health and Safety Management Frameworks (OHSMF) and occupational injuries and accidents in the Ghanaian oil and gas industry: assessing the mediating role of safety knowledge, BioMed Research International (2020) Article ID 6354895. DOI: https://doi.org/10.1155/2020/6354895

[26] Pro zatverdzhennya Poryadku atestatsiyi laboratoriy na provedennya hihiyenichnykh doslidzhen′ faktoriv vyrobnychoho seredovyshcha i trudovoho protsesu: Nakaz Ministerstva sotsial′noyi polityky Ukrayiny, Ministerstva okhorony zdorov″ya Ukrayiny vid 29.05.2018r. № 784/1012. Available from: https://zakon.rada.gov.ua/rada/show/z0905-18/print

[27] Pro zahal′noobov″yazkove derzhavne sotsial′ne strakhuvannya: Zakon Ukrayiny vid 23.09.1999 № 1105-XIV. Vidomosti Verkhovnoyi Rady Ukrayiny. № 46-47, 1999, st. 403. Available from: https://zakon.rada.gov.ua/laws/show/1105-14#Text

[28] Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work. Official Journal L 183, 29/06/1989 P. 0001-0008. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:31989L0391&from=EN

[29] DSTU IEC/ISO 31010:2013. Keruvannya ryzykom. Metody zahal′noho otsinyuvannya ryzyku (IEC/ISO 31010:2009, IDT). Kyyiv: Minekonomrozvytku Ukrayiny, 2015, 80 s. Available from:

https://khoda.gov.ua/image/catalog/files/dstu%2031010.pdf

[30] A.P. Bochkovs′kyy, N.YU. Sapozhnikova, Rozrobka avtomatyzovanoyi systemy minimizatsiyi profesiynykh ryzykiv, Ecological Safety and Balanced Use of Resources 1(17) (2018) 57-65.

[31] Z.M. Radzhab, V.A. Zaloha, A.V. Yvchenko, N.V. Sushchenko, Ynstrumentaryy vybora ratsyonal′noho metoda otsenky ryska pry razrabotke, vnedrenyy y uluchshenyy yntehryrovannoy systemy upravlenyya, Suchasni Tekhnolohiyi v Mashynobuduvanni 8 (2013) 281-297.

[32] O.YE. Kruzhylko, O.V. Bohdanova, Osoblyvosti zastosuvannya modyfikovanoho matrychnoho metodu otsinyuvannya vyrobnychoho ryzyku, Teoriya i Praktyka Budivnytstva 15 (2015) 19-23.

[33] BS OHSAS 18004:2008, Guide to achieving effective health and safety performance, British Standards Institution (BSI), 2008, 150 p.

[34] M. Elmontsri, Review of the strengths and weaknesses of risk matrices, Journal of Risk Analysis and Crisis Response 4/1 (2014) 49-57.
DOI: https://dx.doi.org/10.2991/jrarc.2014.4.1.6

[35] O.V. Bohdanova, Kombinovanyy metod otsinky ryzyku travmatyzmu dlya promyslovoho pidpryyemstva, Problemy Okhorony Pratsi v Ukrayini 31 (2016) 52-63.

[36] Derzhavni sanitarni normy ta pravyla. Hihiyenichna klasyfikatsiya pratsi za pokaznykamy shkidlyvosti ta nebezpechnosti faktoriv vyrobnychoho seredovyshcha, vazhkosti ta napruzhenosti trudovoho protsesu: Nakaz MOZ Ukrayiny vid 08.04.2014 r № 248. Ofitsiynyy visnyk Ukrayiny, № 41, 2014, S. 94. Available from: https://zakon.rada.gov.ua/laws/show/z0472-14

[37] DSN 3.3.6.037.99. Sanitarni normy vyrobnychoho shumu, ul′trazvuku ta infrazvuku: Postanova Holovnoho Derzhavnoho sanitarnoho likarya Ukrayiny vid 1.12.1999 r. № 37.
Available from: https://dnaop.com/html/1642/doc-%D0%94%D0%A1%D0%9D_3.3.6.037-99

[38] DSN 3.3.6.042-99. Sanitarni normy mikroklimatu vyrobnychykh prymishchen′: Postanova Holovnoho derzhavnoho sanitarnoho likarya Ukrayiny vid 1.12.1999 r. № 42.
Available from: https://dnaop.com/html/31675/doc-%D0%94%D0%A1%D0%9D_3.3.6.042-99

[39] A.P. Bochkovs′kyy, Naukovi osnovy upravlinnya ryzykamy vynyknennya profesiynykh nebezpek: dys. … dokt. tekhn. nauk : 05.26.01. Dnipro, 2019. 385 s.

[40] YU.M. Lyakh, Optymizatsiya upravlinnya ryzykamy na pidpryyemstvi naftohazovoyi promyslovosti. Visnyk Kremenchuts′koho Natsional′noho Universytetu imeni Mykhayla Ostrohrads′koho 3 (2019) 107-112.