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Original Article

The Development of a Risk Management System in the Field of Industrial Safety in the Republic of Kazakhstan

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ABSTRACT

Background: The purpose of the work is to develop a system that allows processing of information for analysis and industrial risk management, to monitor the level of industrial safety and to perform necessary measures aimed at the prevention of accidents, casualties, and development of professional diseases for effective management of industrial safety at hazardous industrial sites.
Methods: Risk assessment of accidents and incidents is based on expert evaluations. Based on the lists of criteria parameters and their possible values, provided by the experts, a unified information and analytical database is compiled, which is included in the final interrogation questionnaires. Risk assessment of industrial injuries and occupational diseases is based on statistical methods.
Results: The result of the research is the creation of *Guidelines for risk management on hazardous industrial sites of the Republic of Kazakhstan*. The Guidelines determine the directions and methods of complex assessment of the state of industrial safety and labor protection and they could be applied as methodological basis at the development of preventive measures for emergencies, casualties, and incidents at hazardous industrial sites.
Conclusion: Implementation of the information-analytical system of risk level assessment allows to analyze the state of risk of a possible accident at industrial sites, make valid management decisions aimed at the prevention of emergencies, and monitor the effectiveness of accident prevention measures.

1. Introduction

Analysis of international practice in the field of industrial safety showed that the issues of hazard monitoring and risk prediction of emergencies of natural, natural–technogenic, and technogenic character have a special significance. The assessment of material and financial reserves necessary for localization and liquidation of emergency consequences depends on the reliability of hazard identification and assessment of territorial risks.

Emergencies in industrial projects have particularly dangerous consequences due to the detrimental impact not only on the staff but also, first and foremost, on the environment, due to oil spills and release of highly toxic substances on land and in water. In this way, in 2010 in the Gulf of Mexico the explosion on the Deepwater Horizon oil platform occurred as a result of oil release. The fire that lasted 36 hours happened after the powerful explosion. As a result, the platform sank, the number of casualties amounted to 11 people, and 17 were injured to varying degrees. The result was a damaged pipeline, through which oil flowed from the seabed to the platform board. In total, 4.9 million barrels of crude oil spilled into the waters of the Gulf of Mexico over 86 days. BP has made numerous and mostly unsuccessful attempts to repair the leak. Prior to development of this oil deposit, experts in the BP company evaluated the probability of an oil spill as a result of this well drilling as “low.”

The disaster that occurred August 12, 2015 at Tianjin trade port in North China was named the largest non-nuclear emergency in the history of mankind. It is difficult to imagine a worse place for a fire. Reserves of oil and coal, cyanides, and other toxic substances were kept there. A series of new explosions followed after the first one, the power of which was estimated as equivalent to 12.55×10^9 J; the largest one was estimated as 87.86×10^9 J. As a result of the explosions, at least 145 people were killed and more than 800 were

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injured. The cause of the explosions is considered to be a detonation of explosives in one of the containers. The explosion destroyed the hazardous chemicals warehouse. The Chinese authorities found about 700 tons of sodium cyanide in the epicenter of the destruction zone. This chemical, used to extract precious metals from ore, is not flammable, but it is extremely harmful for human health; its impact on the body is comparable to the toxicity of potassium cyanide. The emergency caused an ecological disaster in the area.

The current international normative framework in the field of risk assessment and management contains, as its basis, the general principles and directions, which have an advisory character for use in practice. The principles contained therein give an idea of the selection and application of systematic techniques for risk assessment; however, they do not present specific criteria for determining the need for risk analysis, and do not define the type of risk analysis method necessary for special application [1–7].

The increased technological complexity of accidents, the development and implementation of industrial and international standards, and a steady trend of transition of activities from emergency liquidation to their prevention and risk management were prerequisites for the development of the risk management information system in the field of industrial safety.

Development of measures to prevent emergencies, reduce the risk of accidents, improve safety and working conditions require from enterprises' managers the ability to manage industrial safety, to implement organizational action on the system human being–industrial process with the aim of achieving a safe level of enterprise functioning. In solving industrial safety management issues, a lot of information, expressed by a number of indexes of different nature and structure, is used. It is necessary to use a well-developed system that allows organization and processing of information for analysis and industrial risk management, to monitor the level of industrial safety in order to respond rapidly to changing factors affecting the protectiveness state of hazardous industrial sites, and fulfillment of necessary measures aimed at the prevention of accidents, casualties, and development of professional diseases for effective management of industrial safety on hazardous industrial sites.

Timely planning and implementation of measures to reduce risks and mitigate the consequences of accidents and casualties at hazardous industrial sites is impossible without analysis of statistical data on the casualties, theoretical research of the technological processes' reliability, modeling of risk situations, assessing the risk of casualties. All this is an important part of the measures aimed at improving protection of population and territories from emergencies of technogenic character.

Currently in the Republic of Kazakhstan, increasing attention is paid to the issue of improving control of the safety level at industrial sites of various branches of industry. Modern requirements of the legislation of the Republic of Kazakhstan, harmonization with the international system of labor safety standards, and the development and implementation of regulatory documentation allow to increase the level of industrial safety.

According to the Decree of the President of the Republic of Kazakhstan from February 27, 2014 No. 757 *On cardinal measures to improve conditions for entrepreneurial activity in the Republic of Kazakhstan*, a transition to organizing inspections of industrial enterprises based on risk assessment is necessary.

There is an active effort in the Republic of Kazakhstan in this direction, to create a unified system of risk control in the field of industrial safety.

For many years, our research team has carried out a retrospective analysis of statistical data in the field of industrial safety and professional sickness rate in the Republic of Kazakhstan. The amount of data obtained (statistical data for the last 10 years were analyzed) allowed us to reliably reveal the number of regularities that formed the basis of the represented methodology, which was reflected in the articles and conference materials devoted to the problems of accidents [8–11], industrial trauma [12–14], and professional sickness rate [15–18].

According to the data of the Emergency Management Committee of the Republic of Kazakhstan, in 2016 in the Republic of Kazakhstan, the share of technogenic emergencies of the total number of emergencies was 88%. Enterprises of the mining and metallurgical complex take the second place after the building industry in terms of the number of traumatized employees. The issues of occupational safety, accident rate, and high level of occupational trauma are especially important for mining industry because about 35% of all registered victims of casualty in the course of labor activity in the country worked in the coal and mining industry. In this regard, despite the need to create a universal methodology for enterprises in various industries, research was focused primarily on the mining industry.

This article summarizes the research carried out and presents the main principles of the methodology for risk management at hazardous industrial sites of the Republic of Kazakhstan. The basis of the methodology is monitoring, allowing to assess the state of accident rate, trauma and professional sickness rate at industrial sites, and to make a motivated and objective conclusion about the degree of hazard and insalubrity of an enterprise.

2. Materials and methods

Risk assessment of accidents and incidents is based on expert evaluations, the essence of which is an organized collection of opinions and assumptions of experts with the subsequent processing of their answers and compiling of results. The method of expert evaluations is less sensitive to inaccuracies and impreciseness of the input data and promotes simultaneously the ability to consider dozens of disparate input parameters. Based on the lists of criteria parameters and their possible values, provided by the experts, a unified information and analytical database is compiled, which is included in the final interrogation questionnaires.

A rating system in the form of universal linguistic scale is used for questionnaire survey and represented in Table 1. The scale allows us to unify both qualitative and quantitative initial data. The experts use their own experience, intellect, and represented scale spread criterial parameters according to degree of their influence on the possibility of accident beginning.

Risk assessment of industrial injuries and occupational diseases is based on statistical methods.

An integrated analysis and assessment of the risk of a possible accident, injury, and labor conditions' insalubrity of an industrial enterprise is performed based on calculation results.

The main objective of the analysis and assessment of hazard levels at the industrial site is to provide:

- objective information about the state of industrial safety and occupational safety;
- information about the most dangerous, "weak" spots from the point of view of industrial safety and labor protection;
- evidence-based recommendations for risk reduction.

A consolidated analytical report, which includes detailed information on the state of industrial safety and labor protection, at separate industrial subdivisions, and at the industrial enterprise as a whole, is formed according to the results of the calculations. Each section of the report contains tables that allow to provide clear and detailed information for the development of risk reducing measures.

Table 1
Assessment scale of importance (degree of influence) of criterial parameter

Degree of influence	Verbal description of influence degree	Mark	
		Linguistic	Score
Weak	Influence on the beginning/severity of an accident in 0–5% of cases	Very weak	1
	Influence on the beginning/severity of an accident in 5–15% of cases	Weak	2
	Influence on the beginning/severity of an accident in 15–25% of cases	Insignificant	3
Medium	Influence on the beginning/severity of an accident in 25–45% of cases	Lower medium	4
	Influence on the beginning/severity of an accident in 45–55% of cases	Medium	5
	Influence on the beginning/severity of an accident in 55–75% of cases	Upper medium	6
Strong	Influence on the beginning/severity of an accident in 75–85% of cases	Significant	7
	Influence on the beginning/severity of an accident in 85–95% of cases	Strong	8
	Influence on the beginning/severity of an accident in 95–100% of cases	Very strong	9

2.1. Risk of accidents and incidents assessment method at hazardous industrial sites

Classification of industrial enterprises according to the degree of risk of a possible accident is based on the results of risk evaluation, carried out in the main and auxiliary industrial subdivisions of the object.

According to the Law of the Republic of Kazakhstan of April 11, 2014 No. 188-V *On Civil Protection*, an accident is the destruction of buildings, constructions and (or) technical devices, uncontrolled explosion, and (or) outburst of hazardous substances; incident is failure or damage of technical devices used at a hazardous industrial site, as well as deviation from the mode of technological process at hazardous industrial site.

The risk of accidents is understood to be the combination of two elements or components of risk.

The accident hazard index, as the first component, which is quantitatively measured according to established criteria, is the possibility that an accident will happen.

The second component is an index of accident severity, which is characterized by a degree of vulnerability to the destructive factor in the accident of both the staff of industrial site and third parties.

The establishment of a risk class of a possible accident of industrial enterprises is performed in the following stages:

1) evaluation of hazard indexes for all possible types of accidents at the industrial site (subdivision);
2) evaluation of severity indexes for all possible types of accidents at the industrial site (subdivision);
3) determination of the level of accidents' risk at the industrial site (subdivision);
4) determination of the risk class of a possible accident of industrial site.

The possibility of accident occurrence depends on many factors.

The multivariate mathematical models, that allow to make a quantitative evaluation of the relationships between hazard indexes and factors of accident occurrence, are used to determine the first risk component or index of accident hazard.

The source data for the calculations are provided by the enterprise through completion of questionnaires, which contain a list of criteria parameters with their values. The questionnaires are filled out by the workers of all main and auxiliary subdivisions of the enterprise that are subjected to the risk assessment.

The risk index of a possible accident is calculated by the dependence equation (1) based on the data on the degree of influence of a number of criteria parameters {n} and the importance of their values on the possibility of the *i*-th accident:

$$RI_i = \sum_{j=1}^{n} w_j \cdot f_j, \quad (1)$$

where w_j is the proportion of *j*-th criteria parameter; f_j is a rating of the criteria parameter value's importance; and *n* is the number of criteria parameters by type of accident.

The values of the risk indexes of a possible accident, calculated by equation (1), correspond to a definite degree of the risk of a possible accident, as presented in Table 2. The scale has five intervals of values with their corresponding degree of risk of a possible accident: negligible, low, medium, significant, high. The risk index of the accident varies from 0 to 10. When the index is zero, risk of accident is absent, and if index is 7 or more the risk of accident is high.

Based on the data on the influence of vulnerability criteria parameters and the significance of their values on the severity of the *i*-th accident, the vulnerability index of people in the zone of a destructive factor is calculated according to dependence (2):

$$VI_i = \sum_{j=1}^{3} a_j y_j, \quad (2)$$

where a_j is the proportion of j-th vulnerability criteria parameter; and y_j is the rating of the significance of the criteria parameter of vulnerability value.The vulnerability index calculated by equation (2) corresponds to the degree of human vulnerability at the industrial site during the accident (Table 3).

Calculation of the level of accidents' risk is performed based on different combinations of the risk components:

1) Indexes of accident risk and human vulnerability;
2) Indexes of accident risk and the possible number of victims among third parties.

The matrix presented in Tables 4 and 5 is applied for the convenience of the procedure the risk evaluation. They have five risk levels, which are highlighted and color-coded: very low, minor, moderate, high, and critical. The maximum possible number of third party victims in the accident for Table 5 is defined in the declaration of industrial safety of the industrial site.

The risk level for each type of accident for all industrial subdivisions of the object is determined from the calculated hazard

Table 2
Scale for determination of accident risk at the industrial site

Value intervals of the accident hazard index	Degree of the risk of a possible accident
$RI_i = 0$	None
$0 < RI_i \le 2$	Negligible
$2 < RI_i \le 3$	Low
$3 < RI_i \le 5$	Medium
$5 < RI_i \le 7$	Significant
$7 < RI_i \le 10$	High

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Table 3
Scale for assessment of people vulnerability degree

Vulnerability Index (VI_i)	Vulnerability degree	Description of vulnerability degree
1	2	3
$VI_i = 0$	None	The people in the area of the destructive factor are not vulnerable. The destructive factor cannot harm their health because they have enough time and possibilities for evacuation, taking shelter in protective constructions, and use of required personal protective equipment.
$0 < VI_i \leq 1$	Low	A small portion of people is vulnerable because they have limited time and possibility for evacuation, taking shelter in protective constructions, and use of required personal protective equipment. Possible loss could be up to 5% of the total number of people who are in the danger zone.
$1 < VI_i \leq 2$	Medium	People who are in the zone of the destructive factor action do not have sufficient time and opportunity for evacuation, taking shelter in protective constructions, and use of required personal protective equipment. Potential losses range from 5% to 15% of the total number of people who are in the danger zone.
$2 < VI_i < 3$	Significant	The majority of people in the zone of destructive factor action are vulnerable because the time factor and the condition of means of collective and individual protection are becoming threatening. Probable losses are from 15% to 25% of the total number of people who are in the danger zone.
$VI_i = 3$	High	People who are in the zone of a destructive factor action are completely vulnerable. They have neither the time nor the possibility of evacuation, taking shelter in protective constructions or use of required personal protective equipment. The number of victims could reach <25% of the total number of people who are in the danger zone.

Table 4
Matrix of accidents' risk level evaluation for the staff of industrial sites

Accident hazard index	Index of people vulnerability				
	0	0–1	1–2	2–3	3
0	None	None	None	None	None
<2	None	Very low	Minor	Moderate	High
2–3	None	Minor	Moderate	High	High
3–5	None	Moderate	High	High	Critical
5–7	None	High	High	Critical	Critical
>7	None	High	Critical	Critical	Critical

and severity indexes of the accident and the data of Tables 4 and 5. For each accident type, the highest level obtained is selected as the overall level of the accident risk for the industrial subdivision.

The highest accident risk level received for the industrial subdivisions of the object is selected as the accident risk level for industrial enterprise as a whole.

2.2. *Risk assessment method of industrial trauma at hazardous industrial sites*

Classification of industrial enterprises according to the degree of injury risk is based on the results of the industrial injury risk assessment both in the individual subdivisions and the object as a whole.

There are two criteria that are applied for the industrial injury risk assessment: the frequency and severity of the injury (disability). The frequency rate of industrial injury is calculated according to equation (3):

$$C_F = \frac{n}{N}, \tag{3}$$

where n is the number of injured employees at the enterprise over the past year; and N is the average number of employees at the enterprise over the past year.

Assessment of the frequency of industrial injury at an industrial enterprise is conducted according to Table 6.

For the acceptable industrial injury risk, the value 10^{-6} is adopted as the maximal permissible value for any risk, including industrial.

The assessment of the severity of an employee's industrial injury is conducted based on the by their long-term loss of overall work

Table 6
Degree of industrial injury frequency

Coefficient of industrial injury frequency (C_F)	Degree of industrial injury frequency
$C_F = 0$	None
$C_F \leq 10^{-6}$	Minor
$10^{-6} < C_F \leq 10^{-5}$	Low
$10^{-5} < C_F \leq 10^{-4}$	Moderate
$10^{-4} < C_F \leq 10^{-3}$	Significant
$10^{-3} < C_F \leq 10^{-2}$	High
$C_F > 10^{-2}$	Very high

Table 5
Matrix of evaluation of accidents' risk level at industrial site for third parties

Accident hazard index	The maximal probable number of victims									
	0	< 10	10–75	75–150	150–300	300–750	750–1,500	1,500–2,000	2,000–4000	>4,000
0	None	None	None	None	None	None	None	None	None	None
<2	None	Very low	Minor	Minor	Minor	Moderate	Moderate	Moderate	High	High
2–3	None	Minor	Minor	Moderate	Moderate	Moderate	Moderate	High	High	Critical
3–5	None	Minor	Moderate	Moderate	Moderate	High	High	High	Critical	Critical
5–7	None	Moderate	High	High	High	High	Critical	Critical	Critical	Critical
>7	None	High	High	Critical	Critical	Critical	Critical	Critical	Critical	Critical

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capacity. The establishment of the degree of disability is fulfilled by medical and social examination.

For the enterprise as a whole, the index for injury severity to the health of workers as a result of industrial injury is determined from the degree of long-term disability by equation (4):

$$IIS_j = \frac{\sum_{i=1}^{n} w_i}{n}, \quad (4)$$

where n is the number of injured workers at the enterprise; and W is the value of long-term loss of overall ability to work of the i-th victim as determined by the medical and social expert commission.

The number of workers injured at the enterprise as result of accident is taken to be n and used for risk assessment of industrial injury as a result of accidents.

The number of workers injured on the enterprise as result of an emergency is taken to be N in equations (3) and (4) and used for risk assessment of injury as a result of casualties.

The degree of severity of the harm to workers' health as a result of industrial injuries obtained by equation (4) is evaluated in Table 7.

If one or more casualty with a fatal outcome happened on the industrial subdivision, the degree of industrial trauma at the industrial site as a whole is evaluated as extremely severe.

The matrix represented in Table 8 allows assessment of the risk of industrial injury at the industrial site. It presents various combinations of injury frequency and injury severity and identifies five levels of risk: negligible, minor, moderate, high, and critical.

This methodological approach allows to detail the risk assessment of industrial injury to the level of the subdivision of an industrial enterprise and to assess the risk of injury as a result of an accident for a comprehensive analysis of industrial injury.

2.3. *Risk assessment method of professional sickness rate at hazardous industrial sites*

The risk of development of occupational diseases in workers is evaluated to determine the insalubrity class of an industrial enterprise.

Evaluation of the risk level of occupational diseases development in workers of the industrial site is carried out according to the following criteria:

1) insalubrity class and danger of working conditions in the workplaces of the industrial site;
2) the level of occupational sickness rate over the past year;
3) the index of occupational sickness rate;
4) on the sickness rate (all types of diseases) with temporary disability during the past year (number of cases of disability and number of days of disability).

The insalubrity and danger of workplace working conditions class of the industrial site is the main criterion for evaluation of occupational disease risk and calculation of the insalubrity index of the industrial enterprise. The level of occupational illness rate, the index of occupational illness rate, the illness rate (for all types of diseases) with temporary disability are additional criteria, ensuring a comprehensive assessment of occupational disease risk [19].

The insalubrity and danger of industrial site workplaces' labor conditions class allows identification of suspected risk of occupational diseases (category 2) based on the weight of the evidence, according to the criteria of the United Nations [20]. The proven risk (category 1A) is identified on the basis of additional criteria of occupational disease risk assessment [20,21].

The index of labor conditions insalubrity of the industrial site as a whole, based on the labor condition class on all workplaces of industrial site separately, is identified by the equation (5):

$$II = \frac{\sum_{i=1}^{7} n_i \cdot R_i}{N_p}, \quad (5)$$

where n_i is the amount of industrial site workplaces in the i-th class of labor conditions; R_i is the numerical value of the i-th class of labor conditions (taking the value 1 for class 1; 2 for class 2; 4 for class 3.1; 8 for class 3.2; 16 for class 3.3; for 32 for class 3.4; 64 for class 4); N_p is the total number of workplaces of the industrial site.

The risk level of occupational diseases at the industrial site as a whole is determined according to the calculated value of index of labor conditions' insalubrity and represented in Table 9.

Similarly, it is possible to determine the index of industrial site insalubrity due to a specific harmful factor and to assess the risk level of occupational disease development for which it is the leading etiological factor. In this case, in equation (5) the class of labor conditions is determined according to the selected harmful factor.

3. Results and discussion

The result of the research is the creation of *Guidelines for risk management on hazardous industrial sites of the Republic of Kazakhstan*.

The Guidelines aim to conduct a comprehensive analysis and assessment of the industrial safety condition at hazardous industrial sites and establish methodological principles and common approaches for the procedure of determining industrial enterprises' danger level.

Table 7
Degrees of injury severity to the health of workers as a result of industrial traumas

Index of injury severity to the health of workers (*IIS*), %	Degree of injury severity to the health of workers
$IIS = 0$	None
$IIS \leq 10$	Slight
$10 < IIS \leq 33$	Medium
$33 < IIS \leq 100$	Severe
The presence of one or more fatal casualty	Extremely severe

Table 8
Matrix to assess the risk level of industrial injury at industrial sites

Degree of industrial injury frequency	Degree of health injury severity			
	Slight	Medium	Severe	Extremely severe
Minor	Negligible	Minor	Moderate	High
Low	Minor	Moderate	Moderate	High
Moderate	Moderate	Moderate	High	Critical
Significant	Moderate	High	High	Critical
High	High	High	Critical	Critical
Very high	High	Critical	Critical	Critical

Table 9
Risk level of occupational disease development, depending on the index of the labor conditions' insalubrity at the industrial site

II	Risk level of occupational disease development at the industrial site as a whole
$II = 1$	Absence of risk
$II \leq 2$	Negligible (endurable) risk
$2 < II \leq 4$	Low (minor) risk
$4 < II \leq 8$	Moderate (essential) risk
$8 < II \leq 16$	High (unendurable) risk
$16 < II \leq 32$	Very high (unendurable) risk
$32 < II \leq 64$	Extremely high risk

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The Guidelines determine the directions and methods of complex assessment of the state of industrial safety and labor protection and they could be applied as methodological basis at the development of measures for the prevention of emergencies, accidents and casualties at hazardous industrial sites.

The main function of the risk management system is the monitoring of industrial safety at hazardous industrial sites. The overall objective of the monitoring system is to conduct a comprehensive analysis and assessment of accident, injury, and occupational disease rate at the industrial sites. As a result of this analysis, enterprises are classified according to the degree of risk and insalubrity of their activity. To fulfill this purpose, it is necessary to achieve several objectives:

- assessment of the accidents' risk level and the determination of accident risk class of the industrial site;
- risk assessment of industrial injury level and the determination of injury risk class of the industrial site;
- risk assessment of occupational diseases level among workers and the determination of insalubrity class of the industrial site;
- detailed analysis and assessment of the risk of a possible accident, injury danger and insalubrity of the labor process, both for separate industrial subdivisions and the industrial enterprise as a whole.

An integrated approach to the monitoring system allows to conduct objective and comprehensive assessment of the state of industrial safety and labor protection at hazardous industrial sites.

Fig. 1 demonstrates the block diagram of the information and analytical system of the hazard level monitoring at hazardous industrial sites.

The Guidelines have a unified structure, which can be used by enterprises of various industries for risk assessment, industrial safety, and labor protection state analysis.

The Guidelines have a systematic branching approach to the assessment of technological risks. This approach justifies the choice of risk assessment methods, which also allows, if necessary, the use of more targeted methods of analysis, evaluation, and processing of risks of individual processes.

For an objective assessment of the hazard level of an industrial enterprise, it is necessary to have criteria that are the basis for judgments about the degree of manufacture safety. They should take into account all activities of organizations operating at hazardous industrial sites, even within the same industry. The use indexes that are standardized for various industries is necessary for industrial safety level assessment.

Most difficult and laborious is the problem of compiling a unified information-analytical database that contains the list of criteria parameters and their possible values, provided by the experts. The difficulty lies in the fact that it is necessary to generate a representative data set of grouped sets of the criteria parameters describing every possible kind of accident that can occur at the separate subdivisions of the enterprise, taking into account characteristics of the industrial process.

The presented methodology was tested and received positive feedback from the supervisory organizations in the field of industrial safety of the Republic of Kazakhstan (Paramilitary Emergency Rescue Service *Komir*, Emergency Management Departments of Karaganda and East Kazakhstan regions), a research institute (*National Centre of Labor Hygiene and Occupational Diseases* of the Ministry of Healthcare of the Republic of Kazakhstan), and a number of mining enterprises (Kazakhmys Corporation LLP, Coal Department of Arcelor Mittal Temirtau JSC). This methodology is used to assess the level of hazard of industrial enterprises in the Republic of Kazakhstan [22].

As an example of the application of the presented methodology, let us consider the risk assessment of accidents, work-related traumas and occupational diseases at the Shakhtinskaya mine of the Coal Department of ArcelorMittal Temirtau JSC.

3.1. Approbation of multifactorial models of the risk of accidents, work-related traumas and occupational diseases on the example of Shakhtinskaya coal mine

The possibility of an accident depends on many factors; therefore, multifactorial mathematical models are used to determine the hazard indicator of accidents, which allows to obtain a quantitative assessment of the relationships between the hazard indicator and the factors of the occurrence of the accident.

The development of a multifactorial model involves an assessment of the influence of factors on the value of the function. It is very difficult to assess the influence of factors in a multifactorial model, because the most part of them does not have a quantitative relationship with the output parameter of the model. Therefore, much attention paid to the choice of the method of mathematical model development for determination the quantitative ranking of factors by the degree of their impact in the development, when the multifactorial model of the accident was created.

The casualty rate analysis at industrial enterprises showed insufficient information on accidents, so the available sample of accident statistics is not representative, i.e., it does not make it possible to draw conclusions about the totality, relying on information on a part of the totality.

Therefore, in the process of mathematical modeling of the accident's hazard index at enterprises, it is proposed to use the method of expert assessments to determine the quantitative ranking of factors by the degree of their influence. The essence of this method is the organized collection of judgments and assumptions of experts followed by the processing of the received answers and the formation of results.

An enterprise should provide certain information by filling in questionnaires for the accident's hazard index determination. As examples, Appendices I and II are questionnaires for gathering information for accident risk assessment in the coal mines of the Republic of Kazakhstan. These questionnaires are formed taking into account the opinions of experts in this field (experts). These questionnaires were sent to the Coal Department of ArcelorMittal Temirtau JSC for data collection and accident risk assessment.

Experts provide the data on the degree of influence of the set of criterial parameters {n} and the importance of their values for the possibility of the occurrence of the i-th accident at mining enterprises that develop underground deposits. These data are used for calculation of the number of hazard indexes:

A) Hazard index of the occurrence of collapse of the roof and the sides of the excavation in coal mine has the form shown in equation (6):

$$R_c = 0.251 \cdot (P_1 + P_2) + 0.201 \cdot P_3 + 0.414 \cdot P_4 + 0.355 \cdot P_5, \tag{6}$$

where P_1 is an importance rating of the stability class of roofing; P_2 is an importance rating of the presence in the zone of influence of second working or the worked out space of adjacent drifts; P_3 is an importance rating of the depth of work; P_4 is an importance rating of the presence of a discontinuous fault zone; and P_5 is an importance rating of the violation of the passport of fixing development coal-faces.

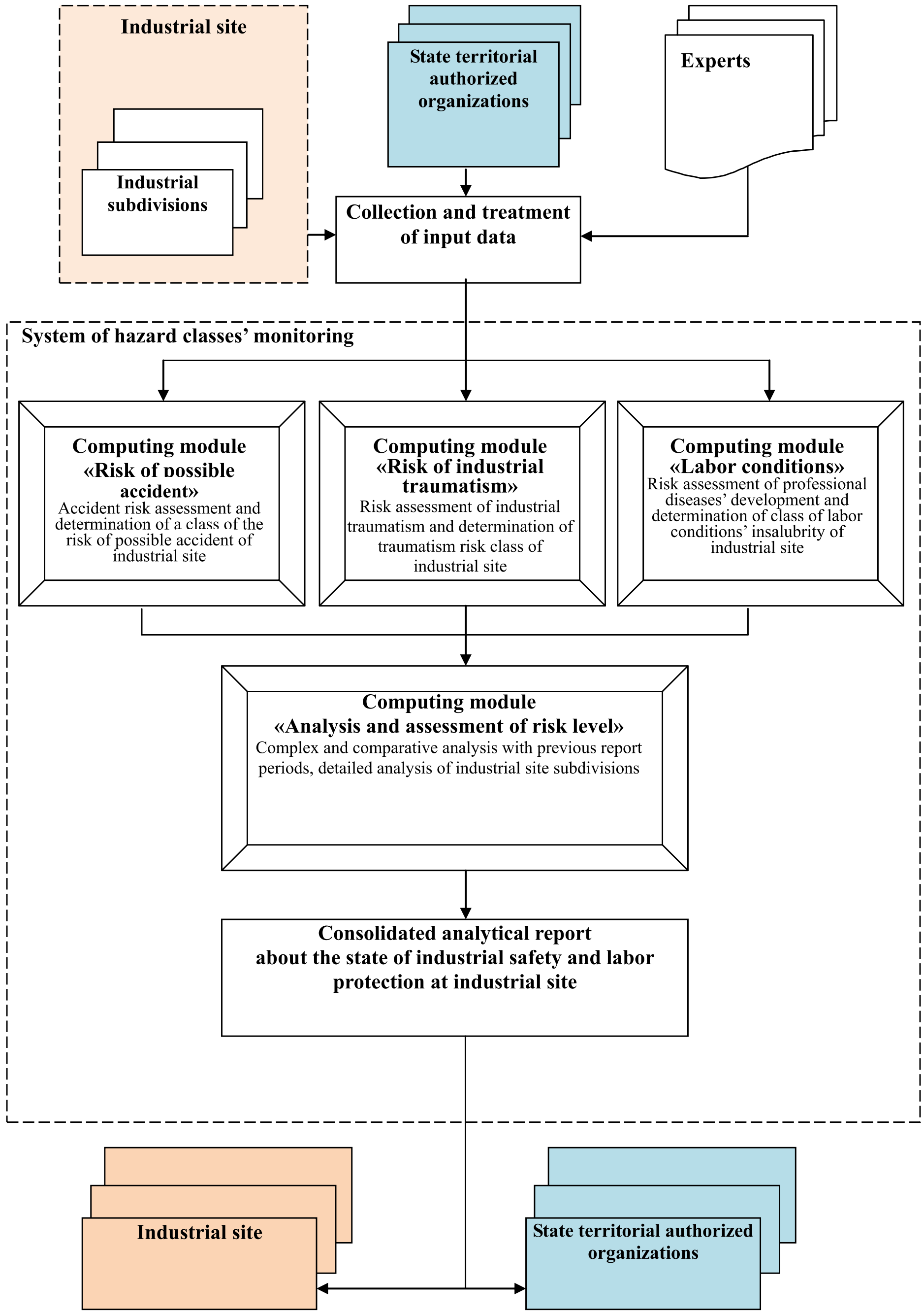

Fig. 1. Block diagram of the information – analytical system of the hazard level monitoring at hazardous industrial sites.

B) Hazard index of the manifestation of dynamic and gas-dynamic phenomena in coal mines has the form shown in formula (7):

$$R_{GDPh} = 0.472 \cdot (P_1 + P_2 + P_3), \quad (7)$$

where P_1 is an importance rating of the burst hazard category of coal seam; P_2 is an importance rating of the presence of a discontinuous fault zone; and P_3 is an importance rating of the violation of preventive measures against sudden outburst of coal and gas.

C) Hazard index of the beginning of endogenous fires in coal mines has the form shown in equation (8):

$$R_{end} = 0.408 \cdot P_1 + 0.152 \cdot P_2 + 0.306 \cdot (P_3 + P_4 + P_5), \quad (8)$$

where P_1 is an importance rating of the liability of the coal seam to spontaneous combustion; P_2 is an importance rating of the depth of work; P_3 is an importance rating of the speed of the development face movement; P_4 is an importance rating of the coal losses; and P_5 is an importance rating of the amount of air entering the production unit.

D) Hazard index of the beginning of exogenous fires in coal mines is determined by equation (9):

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$$R_{ex} = 0.366 \cdot (P_1 + P_2) + 0.395 \cdot (P_3 + P_4), \quad (9)$$

where P_1 is an importance rating of the breach of the integrity of the sheath of power cables; P_2 is an importance rating of the conveyor belt transport's malfunctions, including blocking devices; P_3 is an importance rating of the breach of explosion protection of electrical equipment; and P_4 is an importance rating of the violation of safety in the exploitation of belt conveyors.

E) Hazard index of the explosion of a dust/gas mixture in coal mines is determined by equation (10):

$$R_{\text{exp}} = 0.183 \cdot P_1 + 0.152 \cdot P_2 + 0.091 \cdot (P_3 + P_4) + 0.061 \cdot P_5 + + 0.229 \cdot (P_6 + P_7) + 0.244 \cdot (P_8 + P_9), \quad (10)$$

where P_1 is an importance rating of the methane-bearing capacity of a coal seam; P_2 is an importance rating of the intensity of dust deposit; P_3 is an importance rating of the volatile-matter content; P_4 is an importance rating of the natural wetness of the seam; P_5 is an importance rating of the presence of strong sandstones in the rock massif (for primary working) or the presence of solid pyritic inclusions in the coal seam (for secondary working); P_6 is an importance rating of the violation of ventilation, insecurity of the projected amount of air; P_7 is an importance rating of the absence or malfunction of air–gas monitoring equipment; P_8 is an importance rating of the measures for dust explosion prevention of excavations; and P_9 is an importance rating of the violation of the dust and gas regime.

The indexes were calculated for all production and driving units of Shakhtinskaya mine. The total hazard indexes for accident hazard in the mine as a whole are taken to the maximum value. Table 10 contains the results of the calculations, where the hazard indexes are highlighted in accordance with the hazard degree.

As a result of calculations, it turned out that at the time of research of coal enterprises, the risk of collapse of the roof and sides of the excavation in Shakhtinskaya mine has a critical level, which is highlighted in the appropriate color. Risk of gas-dynamic phenomena and explosion of the dust/gas mixture also has critical values. There is no danger of exogenous fires in the researched sites of Shakhtinskaya mine. Calculations for the Shakhtinskaya mine showed that this site has a high risk of endogenous fires.

The degree of miners' vulnerability was determined during the occurrence of an emergency for accidents' risk assessment. The following values of the vulnerability criteria are determined for assessment of the risks of collapse of the roof and sides of the excavation, the manifestation of gas-dynamic phenomena and explosions of the dust-gas mixture:

- presence of the time for evacuation and other special measures when an accident happens is 3;
- characteristic of protective constructions and other means of collective protection is 3;
- characteristic of personal protective equipment is 3.

The index of vulnerability of people in the affected zone of these types of accidents, computed by equation (2), is equal to 3. Comparison of these indexes with the data of Table 3 indicates a high degree of vulnerability of miners during the collapse of the roof and sides of the excavation, the manifestation of gas-dynamic phenomena and explosions of dust-gas mixture. Workers who are in the zone of effect of the damaging factors are completely vulnerable. They have neither the time nor the opportunity to leave the danger zone.

The following values of the vulnerability criteria are determined for the assessment of endogenous and exogenous fire hazard:

- presence of the time for evacuation and other special measures when an accident happens is 0;
- characteristic of protective constructions and other means of collective protection is 1;
- characteristic of personal protective equipment is 1.

The index of vulnerability of people, when exogenous fires at this mine begin, is 0, which indicates an insignificant degree of vulnerability of miners (Table 3).

The risk of accidents was assessed at the researched units of Shakhtinskaya mine, based on the computed hazard indexes and the predetermined degree of human vulnerability. Table 11 presents the results of accidents' risk assessment in Shakhtinskaya mine.

The maximum possible number of victims was accepted 0, when class of risk of a possible accident in relation to third parties was established for accidents' risk assessment. Thus, there is no risk for third parties at the researched industrial site.

It was found that one miner had clavicle fracture and multiple bruises as a result of collapse of the roof of the excavation during the collection of data for the previous year for the risk assessment of occupational injuries. The index of the severity of damage to health was 20%, which according to Table 7 appropriates to the medium degree of injury severity to the health. At the same time, the average number of workers in the mine was 1560, that is, according to Table 6, a significant degree of frequency of industrial injuries in Shakhtinskaya mine.

Comparison of obtained results in the matrix, presented in Table 8, indicates high level of occupational injury risk at Shakhtinskaya mine.

Carried out attestation of workplaces according to labor conditions in Shakhtinskaya mine showed that 657 workplaces were appropriated to the class of labor conditions 2, 301 workplaces appropriate to the class of labor conditions 3.1, and 602 workplaces appropriate to the class of labor conditions 3.2.

Table 10
Hazard indexes of accidents computed for Shakhtinskaya mine of the Coal Department of ArcelorMittal Temirtau JSC

Industrial object		Type of accident				
		Collapse of the roof and sides of the excavation	Manifestation of gas-dynamic phenomena	Explosion of a dust/gas mixture	Exogenous fires	Endogenous fires
First working	Air connection 293 D6-nw	6.32	6.42	5.8	0	No data
	Belt entry 238 D6-e	6.32	6.42	5.8	0	No data
	Air roadway 5 D1-2	1.4	0	2.3	0	No data
	Air roadway D1-2	1.4	0	2.3	0	No data
	Conveyor crosscut D1-2 g ± 0 m	1.82	0	0	0	No data
Second working	Face 242 D6-c	No data	No data	5.15	0	8.1
Total		6.32	6.42	5.8	0	8.1

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Table 11
Levels of accident risk in Shakhtinskaya mine of the Coal Department of ArcelorMittal Temirtau JSC

Industrial object		Type of accident				
		Collapse of the roof and sides of the excavation	Manifestation of gas-dynamic phenomena	Explosion of a dust–gas mixture	Exogenous fires	Endogenous fires
First working	Air connection 293 D6-nw	Critical	Critical	Critical	Absents	No data
	Belt entry 238 D6-e	Critical	Critical	Critical	Absents	No data
	Air roadway 5 D1-2	High	Absents	High	Absents	No data
	Air roadway D1-2	High	Absents	High	Absents	No data
	Conveyor crosscut D1-2 g ± 0 m	High	Absents	Absents	Absents	No data
Second working	Face 242 D6-c	No data	No data	Critical	Absents	High
Total		Critical	Critical	Critical	Absents	High

The index of labor conditions insalubrity *II* of the industrial site as a whole is determined by equation (5) and its value is 4.44. Comparing the obtained value with the data of Table 9, we determine that the level of risk of development of occupational diseases in Shakhtinskaya mine is moderate (essential).

4. Conclusion

The authors of this paper completed the research, the result of which became development of *Guidelines for risk management on hazardous industrial sites of the Republic of Kazakhstan* with the purpose of their including in the unified system of risk management in the field of industrial safety in the Republic of Kazakhstan.

A cluster of criteria parameters was created along with their possible values for the mining industry, which is included into a single information-analytical database taking into account features of technological process.

Implementation of the information-analytical system of risk level assessment allows to objectively and quickly analyze the state of risk of a possible accident at industrial sites, make valid management decisions aimed at the prevention of emergencies and monitor the effectiveness of accident prevention measures, as well as comprehensively approach a solution to the problem of increasing industrial safety and labor protection at industrial sites in the Republic of Kazakhstan.

Currently, the creative team is working on the development of information-analytical database, creating a cluster that contains a list of criteria parameters and their possible values of the enterprises of the chemical, oil and gas industry of Kazakhstan.

Conflicts of interest

There are no potential conflicts of interest that could influence the author's interpretation of the data.

Appendix A.

Questionnaire for collecting initial information from coal mines.

No.	Criterial parameter		Possible values of criterial parameters		Actual value of the criterial parameter
	Name	Shared part	Name	Assessment the importance of the value	
1	2	3	4	5	6
For assessment of the risk of collapse of the roof and sides of the excavation during the first working					
1	Presence of a discontinuous fault zone	0.31	Doing works in the discontinuous fault zone Approaching the discontinuous fault zone Doing work outside the discontinuous fault zone	10 5 0	
2	Violation of the passport of fixing development coal-faces	0.24	Yes No	10 0	
3	Presence in the zone of influence of second working or the worked-out space of adjacent drifts	0.1	Yes No	10 0	
4	Depth of work	0.07	<300 m 300–600 m > 600 m	0 6 10	
5	Stability class of roofing*	0.28	Class I Class II Class III	10 5 0	
For assessment of the risk of gas–dynamic phenomena (sudden outburst of coal and gas)					
6	Burst hazard category of coal seam	0.56	Extremely hazardous Hazardous Not hazardous	10 7 0	
7	The presence of a discontinuous fault zone	0.25	Doing works in the discontinuous fault zone Approaching the discontinuous fault zone Doing work outside the discontinuous fault zone	10 5 0	
8	Violation of preventive measures against sudden outburst of coal and gas	0.19	Yes No	10 0	

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(*continued*)

No.	Criterial parameter		Possible values of criterial parameters		Actual value of the criterial parameter
	Name	Shared part	Name	Assessment the importance of the value	
1	2	3	4	5	6
For assessment of the risk of endogenous fires					
9	Liability of the coal seam to spontaneous combustion	0.26	Not liable Liable	0 10	
10	Depth of work (m)	0.21	<300 300–500 500–700 >700	0 4 8 10	
11	Speed of the development face movement (m/mo)	0.21	20–30 30–40 40–50 50–60 >60	10 5 4 3 0	
12	Coal losses (m)	0.11	<0.5 0.5–1 1–1.5 1.5–2 2–2.5 > 2.5	0 2 4 6 8 10	
13	Amount of air entering the production unit (m^3/min)	0.21	<500 500–1,000 1,000–1,500 >1,500	0 3 7 10	
For assessment of the risk of exogenous fires					
14	Breach of the integrity of the sheath of power cables	0.28	Present Absent	10 0	
15	Conveyor belt transport's malfunctions, incl. blocking devices	0.2	Present Absent	10 0	
16	Breach of explosion protection of electrical equipment	0.28	Present Absent	10 0	
17	Violation of safety in the exploitation of belt conveyors	0.24	Present Absent	10 0	
For assessment of the risk of the explosion of a dust/gas mixture for development faces (except rock faces)					
18	Methane-bearing capacity of a coal seam	0.25	Up to 5 m^3/t 5–10 m^3/t 10–15 m^3/t 15 m^3/t and more grain boundary precipitates Seams that are hazardous for sudden outbursts of coal and gas, as well as burst of hazardous rocks	0 2 5 9 10	
19	Intensity of dust deposit	0.1	≤1.2 $g/m^3 \cdot d$ >1.2 $g/m^3 \cdot d$	0 10	
20	Volatile matter content	0.05	<15% ≥15%	0 10	
21	Natural wetness of the seam	0.05	≤12% >12%	10 0	
22	Presence of strong sandstones in the rock massif (for primary working) or the presence of solid pyritic inclusions in the coal seam (for secondary working)	0.05	Yes No	10 0	
23	Violation of ventilation, insecurity of the projected amount of air	0.15	Yes No	10 0	
24	Absence or malfunction of air-gas monitoring equipment	0.1	Yes No	10 0	
25	Violation of measures for dust explosion prevention in excavations	0.12	Yes No	10 0	
26	Violation of the dust and gas regime	0.13	Yes No	10 0	
For assessment of the risk of methane explosion in rock faces					
27	Concentration of explosive gases in the air of excavation	0.4	≤2% >2%	0 10	
28	Violation of ventilation, insecurity of the projected amount of air	0.3	Yes No	10 0	
29	Absence or malfunction of air-gas monitoring equipment	0.1	Yes No	10 0	

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(*continued*)

No.	Criterial parameter		Possible values of criterial parameters		Actual value of the criterial parameter
	Name	Shared part	Name	Assessment the importance of the value	
1	2	3	4	5	6
30	Violation of measures for dust explosion prevention in excavations	0.1	Yes No	10 0	
31	Violation of the dust and gas regime	0.1	Yes No	10 0	

* Rock stability classes, represented in the table, have the following description:
Class I includes unstable roofing rocks, in which the roofing rocks collapse after being exposed at a distance of 1 m from the face. This class is mainly associated with thinly bedded and fractured mudstones with rock compressive strength Rc $\leq$ 30 MPa.
Class II includes the roof rocks of medium stability, in which the stability is maintained when the roof is exposed at a 1–3 m distance from the face. This layer is mainly associated with layered, slightly fissured siltstones and sandstones with 30 $<$ Rc $\leq$ 80 MPa.
Class III includes stable roof rocks, in which the stability is maintained when the roof is exposed at more than 3 m distance from the face. Mostly they are not fractured sandstones, marls with Rc $>$ 80 MPa.

Appendix B.

Questionnaire for collecting initial information for assessing the people's vulnerability degree at mining enterprises.

No.	Criterial parameter		Possible values of criterial parameters		Actual value of the criterial parameter
	Name	Shared part	Name	Assessment of the importance of the value	
1	2	3	4	5	6
1	Presence of the time for evacuation and other special measures when an accident happens	0.7	People, who are in the dangerous zone, do not have any time for evacuation	3	
			Not every person has enough time for evacuation from the dangerous zone	2	
			All persons, who are in the dangerous zone, have limited time for evacuation	1	
			Whole personnel are able to leave the dangerous zone when the first signs of emergency before accident development become visible	0	
2	Characteristics of protective constructions and other means of collective protection	0.1	Protective constructions, shelter absence, or their condition is unsatisfactory	3	
			Protective constructions present, but their location, amount and dimension cannot shelter all persons who are in the dangerous zone	2	
			Available protective constructions are not so effective to protect against impact of destructive factor	1	
			There are enough protective constructions, they are available for all persons, who are in the dangerous zone	0	
3	Characteristic of personal protective equipment	0.2	Employees are not supplied with required personal protective equipment. Technical condition of the necessary personal protective equipment is unsatisfactory	3	
			Not every employee is supplied with demanded personal protective equipment. Not every personal protective equipment has satisfactory technical condition	2	
			All employees are supplied with personal protective equipment. Condition of personal protective equipment is satisfactory, but they are not so effective against destructive impact of the factor	1	
			Every employee is supplied with personal protective equipment, which completely protects their body against all destructive factors begun as a result of an accident	0	

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