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Determining Priority of Risk Factors in Technological Zones of Longwalls

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Abstract

The studies of risk factors on which the safety of miners depends are relevant. These factors include temperature and air velocity within roadways, relative air humidity, dust, noise and vibration, lighting, clutter, limited working space, the difficulty of work, and the collapse of roof rocks. Their greatest concentration is in the technological zones of longwalls, so it is important to determine the priority of taking into account the risk factors in certain zones for planning measures for labor protection in underground coal mining. Therefore, a matrix of priority of risk factors for technological zone longwalls is proposed. The matrix is based on a survey of experienced and well-informed scientists and engineers of coal mines (experts). Fifty experts are involved in the survey. The matrix assesses the priority of risk factors, and considers the technological zones of the longwalls for the planning labor protection measures. The zones of operation of the excavation machines and the end-sections of longwalls are defined as the most safety-critical. Less safety-critical, but also dangerous, are the zones of protection means and the zones of connection of the longwalls with the roadways. The level of a certain risk factor is determined for each zone. The highest priority should be given to the collapse of roofs, dust, clutter of the working space, and the severity of the miners' work. For each risk factor included in the matrix, the technical and organizational measures for labor protection are proposed to reduce the level of injuries for miners.

1. Introduction

Underground mineral mining has the highest level of occupational injuries [1-6] including those with fatal consequences [1]. At the same time, the coal industry occupies a leading position, although coal mining is characterized by difficult working conditions and complex mining and geological conditions.

The highest level of injuries is observed in miners of longwalls when performing the operations that are part of the technological process of coal mining. On this issue, there are many studies on the analysis of injuries from dangerous and harmful factors, depending on the profession, age, and length of service, geological as well as mining and technical factors, and more [7, 8]. There is a lack of research on injuries at the level of individual operations, which are part of the technological process and are associated with certain jobs [9].

This issue is of particular relevance for the coal mines of Ukraine but it is no less important for the mines in China, Poland, and other countries where the technology of underground coal mining with long pillars is used. Longwall is divided into technological zones (Fig. 1), where certain production operations are carried out in order to ensure sustainable coal mining. Safety of operations at workplaces in technological zones depends on some factors of the production environment and working process (risk factors). These factors are harmful and dangerous to the

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health and lives of the workers. They mask, divert attention, and encourage the workers to use careless and dangerous techniques at work, break the sequence of operations, make mistakes, etc. These factors include temperature and air velocity within roadways, relative humidity of air, dust, noise and vibration levels, lighting intensity, the energy consumption of the worker's body, and the monotony of individual operations. They also include clutter, limited and restricted workplace, and work in awkward positions.

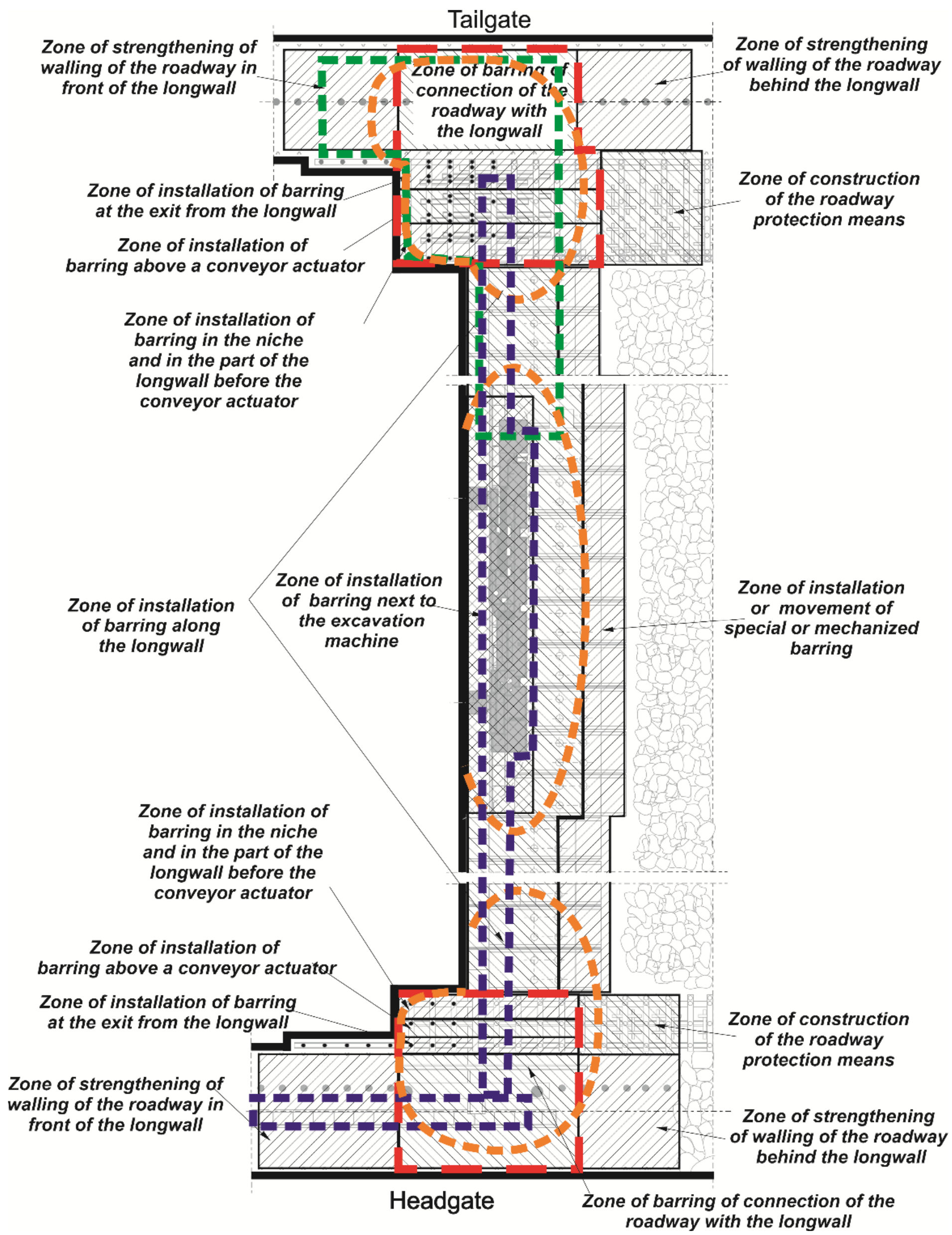

Figure 1. Layout of technological zones in longwall and next to it (▭ - area of high noise level; ▭ - equipment vibration area; ▭ - area of dust in workspace; ▭ -area of most dangerous zones in terms of collapse of the roof rocks).

The working conditions of miners in longwalls differ for different technological zones since the zones have different sets of operations and combinations of risk factors. Therefore, it is extremely important to take into account the risk factors when planning labour protection and safety measures in some technological zones. However, it is not always possible to quantitatively assess the impact of each factor or several such factors on the worker. It is difficult to assess their influence on the injury rate. Complex consideration of the influence of several factors when they are concentrated in a certain set at a certain workplace during the performance of certain operations of the production cycle is especially difficult. As a rule, in each set of factors, there are those for which it is impossible to determine the intensity of manifestation but their impact on the safety of miners is obvious, and can be evaluated only on the basis of the use of the personal opinion of an expert or the collective opinion of a group of experts. At the same time, the experts must take into account the parameters of the external environment, the intensity of the effect of factors on the worker, and track the worker's reaction to the influence of factors, namely, to apply the knowledge of labor physiology, mining and labor protection, which they obtained in the process of training and working. Thus the purpose of the article is to assess the priority of taking into account risk factors in the longwalls based on the conclusion of the experts on labor protection in mining.

To achieve the goal, the article plans to conduct an analysis of the results of research on the establishment of the main risk factors that have an impact on the injury rate of miners in longwalls. Then the factors should be evaluated by the experts from the viewpoint of their influence on the injury rate of tne miners when performing work in the technological zones of longwalls. Based on the assessment of the factors, their priority consideration for the development of labor protection measures can be determined.

2. Literature Review and Relevance of Article

Production operations for underground coal mining are performed by miners in conditions of dust, air vibration, elevated temperatures, barometric pressure, noise, and insufficient lighting, under the influence of high air velocity and humidity. In these conditions, the work of miners is characterized as moderately exhausting or moderately hard, with elements of hard physical labor [10]. Also accompanied by nervous and emotional stress, requires concentration of attention, hearing, vision, and mobility in conditions of limited working space and awkward working positions. Therefore, when developing and implementing measures to prevent injuries, it is necessary to take into account the factors that determine the working conditions of the miners.

The impact of noise on miners leads to an increase in cases of general and occupational sickness and a decrease in the productivity of work. Noise negatively affects the psychology and physiology of working people [11-14], and then it affects their behavior and leads to industrial accidents [15-18]. It has been established that the noise increase from 70 to 90 dBA in the working area requires, on average, over 20% of the worker's physical and neuro-psychological efforts [10]. It is consistent with many scientific research results [11, 19, 20]. Noise masks, isolates a worker from the external environment, warning and emergency signals, and it can also be the cause of an emergency situation and an increase in injuries. It is difficult or even impossible to reduce the noise in longwalls, where there is a high density of machines and mechanisms, high speed of work, and a lack of working space.

There are areas in which the miners are exposed to noise [10]: the area of operation of the excavating machine (noise sources: excavating machine and scraper conveyor); movement zone of barring sections and conveyor (extends 5-10 m from the excavating machine; noise sources: excavating machine, scraper conveyor, movable barring sections); roof control area (located at a distance of 10-20 m from the excavation machine; noise sources: conveyor and noise accompanying roof control operations); extraction zones in the upper and lower niches (noise sources: manual machines, conveyor drive, periodic exposure of the excavation machine). These areas are shown in orange in Figure 1.

Vibration occurs as a result of the operation of mechanisms, wear of surfaces and changes in the geometric parameters of machine parts, the appearance of gaps, and the emergence of additional dynamic loads. The area of increased vibration in the longwall is shown in blue in Figure 1. Vibration is the cause of machine breakdowns, which can injure the workers. Vibration is not always accompanied by machine breakdowns but is a characteristic of the normal mode of their operation. Vibrations during the operation of combines and jackhammers, conveyors, and drilling rigs are inevitable. In essence, these mechanisms are vibrators, the impact of which on the surrounding rocks leads to an imbalance in the system "adjoining rocks–supports", accompanied by deformation processes of rocks on the contour of roadway and collapse into the working space. Thus vibration can be not only the cause of the occupational disease (vibration disease) [21-23] but also the industrial injury to the worker.

The content of dust in the mine atmosphere is also a factor that complicates the working conditions and is a source of occupational diseases (respiratory diseases) [24, 25]. Dustiness of the working space can be an obstacle in assessing the situation in the workplace, limiting the receipt of warning and alarm signals. Permissible norms of dust content in the air of the working area are determined by the rules of safety in coal mines and established from the standpoint of harmful effects on the human body and the possibility of acquiring an occupational disease. The change in the concentration of dust in the air depends on many factors (mining and geological conditions, hardness of rocks, conditions of their occurrence, the method and speed of coal mining and transportation, the availability of irrigation, air velocity in roadway). The highest concentration of dust in the longwalls is on the way from the running mining machine to the exit from the longwall (green area in Figure 1).

Workspace lighting significantly affects the level of occupational safety [26, 27]. With good lighting, it is easier to assess the situation in the workplace (inspect the workplace, surrounding machines, mechanisms, walling, the condition of the surrounding rocks, etc.). However, mostly underground work is performed in low light conditions, when portable rechargeable lamps are used. Permanent lighting is sometimes used in the roadways, on downhole machines and electric locomotives, and in longwalls.

Air temperature poses potential risks to the miners' health and threatens mining efficiency [27, 28]. Sources of heat release in underground mining are the surrounding rock mass, air pressure in the roadway, oxidative processes of rocks and material attachment, machinery, equipment, and people. The relationship between the operating temperature of the environment and the frequency of injuries is well established [29, 30], so the coal mines widely use the technologies for cooling and heating the atmosphere. For certain technological zones of the longwall, it is difficult to establish the relationship between the temperature factor and the safety of work, as there is no information on changes in air temperature along the longwall.

Equally important is the consideration of psycho-physiological working conditions, in particular, indicators of the severity of the labor process, as miners spend most of their working time on physical work of increased severity. Miners experience increased physical activity during the shift, being in forced, uncomfortable working positions during operations. In this case, the value of the total energy expenditure of the body often reaches or exceeds the allowable values long before the end of the shift, so there are earlier signs of developing fatigue. This is especially evident when performing work in certain working positions in the longwalls, where the working space is limited by the thickness of the seam, and the availability of supports, machines, and mechanisms.

The nature of working poses is determined by mining and geological conditions, workplace parameters, values and nature of work effort, clutter of working space, accuracy of operations, degree of attention and visual acuity, level of mechanization and automation, and parameters of supports in longwall. All of these factors, one way or another, affect the level of injuries in specific workplaces. It is quite difficult to establish a connection between traumatism and the accuracy of operations, the degree of attention, and visual acuity of the worker but it is possible to consider the impact of a limited and cluttered workplace, as well level of mechanization on the level of injuries.

Most operations in the longwalls are performed in the movement of machines and mechanisms, intense deformation of the surrounding rock mass as a result of mining, which increases the likelihood of accidents. In these cases, it is necessary to take into account mining-geological and mining-technical factors. The impact of machines and mechanisms can be taken into account by the levels of noise and vibration they generate. Clutter of the workspace can be determined by the area of the workplace. The stability of rocks is characterized by their strength, fracturing, water content, influence rock pressure, and parameters of technological schemes strengthening roadways. Stratification of roof rocks is accompanied by an intensive collapse of rocks into the working space [31], especially in the end sections of longwalls and adjacent roadways, where the geo-mechanical situation in the rock mass is dynamically changing. To prevent collapses in the areas of longwalls, there are technological solutions to strengthen the roof rocks [32-37], reduce the pliability of protective constructions [34, 37-39] and their pressing into the soft rocks of the footwall [39-42], the use of special supports [34, 43-48], filling worked-out space [49, 50], etc.

Analysis of the results of numerical studies shows that most risk factors are considered for a longwall in general without dividing it into separate zones. An exception was the study when the injury in the longwall was considered taking into account the dangerous factors. To do this, the reports of accidents in the longwalls have been studied, and the location of injuries of miners from such factors as rock collapse, the action of machines and mechanisms, falling objects, and falling people, have been investigated [9, 51]. The requirement to take into account mining-geological, mining-technical factors, and working conditions of miners when planning work in the longwall in order to reduce injuries [9] has been substantiated.

It has been established that the largest number of roof collapses occurs in the end sections of longwalls and in adjacent connections with roadways [51]. They belong to the areas marked in red in Figure 1. The impact of workload on the level of injuries can be established by studying the production process in the longwall and determining the energy consumption of miners [52]. However, these injuries are difficult to attribute to a particular technological zone. The situation is similar to other risk factors that affect the safety of miners (limited working space, clutter, dust and lighting, noise levels, and mechanization). Some of these factors are harmful and dangerous, and some are masking. They should not be neglected in the development of labor protection measures, as their influence on the injury rate in certain conditions can be significant. They cannot be equally manifested in different zones. At the same time, each factor in a certain zone has its own degree of influence on the miner's safety.

Therefore, when planning the safety and labor protection measures, it is important to rank these factors according to the relevant zones and determine the sequence of consideration of each factor for further design of mining operations and planning safety and labour protection measures.

3. Materials and research methods

It is possible to reduce the level of injuries in the technological zones of the longwalls by developing technological and organizational decisions at design taking into account the working conditions of miners. It is necessary to provide comfortable and safe working conditions for the worker; otherwise, there is a high probability of injury to the worker when performing heavy work in the presence of masking, distracting, and dangerous production factors. In general, the importance of the application of labor protection measures in technological zones of longwalls, depending on working conditions, can be determined by the priority of taking into account risk factors in each zone.

In many studies, the main quantitative measure of danger is risk–the probability of negative consequences from economic activity [53]. The risks considered are accident [54], casualty [53, 54, 55], injury [56, 57], traumatism [53], fatal injury [58], loss of health [59], occupational disease [60], risk of the workplace [61], the risk of harming the life and health of the worker [62], the risk of roof rocks collapsing [63]. There are also studies on risk prediction in coal mines [64]. In all these works, the authors try to quantify the influence of the relevant factor or several factors on a negative event, in particular on the level of industrial injuries. However, it is not always possible to quantitatively establish the relationship between some factors and the corresponding event. For example, it is difficult to determine the probability of injury to a miner when the degree of clutter in the working space or the intensity of its lighting changes. It is even more difficult to take into account the complex impact of several factors on the injury rate.

Since the impact of most risk factors on the level of injuries can be assessed in qualitative form, it has been proposed to make a matrix of priority factors for the application of labor protection measures in relevant zones based on expert surveys widely used in risk assessment for occupational safety [65-68]. The method of pairwise comparisons has been used for this aim [69].

The purpose of the survey is to expertly assess the degree of influence of a certain risk factor on injuries in each technological zone of the longwall. The method involves the competent participation of specialists (experts) in the analysis and solution of the problem. Therefore, the experienced and well-informed scientists on labor protection and engineering and technical workers of coal mines are involved in the survey. The selection of experts takes into account the competence and independence of the experts, for which the criteria listed in Table 1 are considered.

Table 1. List of criteria and conditions for selection of experts

Criteria for selection of experts	Conditions for selection
Expert position	Engineering worker; Researcher
Expert education	Higher education
Educational qualification level or scientific degree of expert	Master of Mining, PhD, DSc
Specialist in mining and labor protection	Yes
Experience of work or research in the field of underground coal mining	More than 5 years
Consent of the expert to conduct an objective examination	Yes

A questionnaire for the experts has been compiled (Fig. 2), in which they are asked to assess in rank the priority of taking into account a certain risk factor for planning occupational safety measures in the relevant technological zones of the longwall. The highest, middle, and lowest ranks have been proposed, which should be quantified, respectively, 1, 2, and 3. Thus the expert ranks the risk factors for miners in certain zones based on their experience and knowledge.

Expert survey

Expert's name and surname *Oleksandr Dolhobrod* Expert's position *Director of labour protection*

Expert's education *higher* Experience of work of the expert *40*

Assess the priority of taking into account risk factors in certain technological zones to develop and plan measures for labor protection by assigning them a rank number: 1, 2, 3- respectively, high, medium, and low priority.

If in your opinion, the priorities are equal, they are assigned the same rank number.

Numbers of technological zones according to the scheme	Priority of factor consideration in the relevant zone								
	noise	vibration	lighting	dustiness	limited workspace	cluttered workspace	level of mechanization	difficulty of work	collapse of roof rocks
I	1	1	1	1	1	1	1	3	1
II	1	2	1	1	1	1	2	1	1
III	2	3	3	3	3	2	2	3	2
IV	2	1	1	1	1	1	2	1	1
V	2	1	1	1	1	1	2	1	1
VI	2	1	1	1	1	1	2	1	1
VII	3	3	2	2	2	1	2	1	1
VIII	2	2	1	2	3	2	2	2	2
IX	2	3	2	2	3	2	2	2	2
X	3	3	3	3	3	3	3	2	2

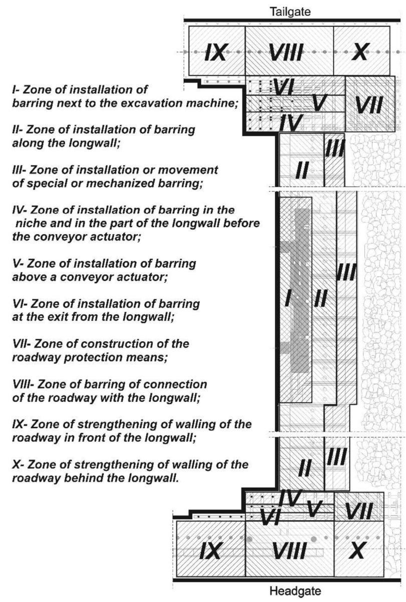

Figure 2. General view of questionnaire for interviewing experts with results of expert's answer

In expert surveys, the number of experts is accepted to be 7, in some cases it reaches 20 people or, if necessary, increases until the growth of the Kendall concordance coefficient is stabilized, which is an indicator of assessing the consistency of expert opinions and determined by the formula [69].

$$W = \frac{12S}{m^2\left(n^3 - n\right)}, \tag{1}$$

where m– is the number of experts; n– the number of factors analyzed; S – is the sum of the squares of the deviations of the sum of the ranks of each object of examination from the arithmetic mean of the ranks, which is determined by the expression [69].

$$S = \sum_{j=1}^{n}\left(\sum_{i=1}^{m} x_{ij} - \frac{\sum_{j=1}^{n}\sum_{i=1}^{m} x_{ij}}{n}\right)^2, \tag{2}$$

where x_{ij} – is the rank of factor j of expert i.

According to the results of the expert survey, the rank of each factor by zones and the rank of each zone by factors are determined. Next, the concordance coefficients are calculated, and the Pearson's experimental criterion is determined from the expression [69].

$$\chi^2 = \left(\frac{S}{\frac{1}{12} mn\left(n+1\right)}\right). \tag{3}$$

A comparison of Pearson's experimental and tabular criteria allows assessing the significance of the concordance coefficient. The excess of the experimental over the tabular indicates that the values of the concordance coefficient are not random, the results are meaningful and can be used in further research works.

In the next stage, the survey matrix is transformed into a rank matrix, for which the ranks of the factor and zone are determined by the formula:

$$r_{ij} = x_{\max} - x_{ij}, \tag{4}$$

where x_{max} – is the maximum rank of factor (zone) $x_{max} = 3$.

After the transformation, the amounts of ranks obtained and their weight are determined in the final assessment of factors and zones. Based on the calculations, a matrix of priority of considering risk factors and considering technological zones for planning occupational safety measures is made. According to the values related to the relevant factor and zone in this matrix, the working conditions are divided into three priority categories: high, medium, and low. The largest value corresponds to the highest category and the most difficult working conditions for miners (the most important factor in the most dangerous technological zone). Less difficult conditions are given lower ratings depending on their value in the end. The factors and zones that are assigned to the highest category should be given priority when planning activities in the longwall.

3. Results and discussion

To determine the impact of risk factors on the safety of miners and to establish the priority of development and planning of labor protection measures in the technological zones of the longwalls, an expert survey has been conducted by questioning the specialists of labor protection in underground coal mining. The experts are representatives of various Ukrainian coal mines, educational institutions, and scientific organizations. They are experienced specialists in underground coal mining. Each of them has his own idea of the technological scheme of the longwall, where coal was extracted (equipped with a combine or planer, with mechanized or individual fasteners, with different ways of managing the roof, etc.).

The mining and geological conditions corresponded to the working conditions of the coal seams of the Donetsk coal basin of Ukraine: a thickness of the seams is from 0.7 to 2.5 m, a depth of development is from 250 to 1150 m, and the dip angles are from 6^0 to 24^o. The coal seam mining technology is adopted by long pillars in length, rise and fall with the use of the shearers with a grip width of the executive parts up to 1 m.

At the initial stage, questionnaires were distributed to 7 experts, who on a three-point scale (1- high priority, 2- medium, and 3- low) assessed the importance of taking into account each of the proposed factors in the relevant zonas (Fig. 2). After that, the results of the survey were processed. Next, the ranks of each risk factor for each technological zone of the longwall and the ranks of each zone according to the factors were determined. The concordance coefficient W and Pearson's experimental criterion χ^2 have been calculated for each factor and individual zone (Table 2). The experimental criterion χ^2 has been compared with the tabular χ^2_{table}. According to the value of the indicators W and χ^2, the agreement of the opinions of experts and their statistical significance have been evaluated.

It has been found that according to the results of the survey of seven experts, the concordance coefficients for all risk factors and assessed zones ranged from 0.15 to 0.76, and Pearson's calculation criterion exceeded the tabular one (Table 2), i.e. there was a low and medium degree of agreement among experts, the values of the concordance coefficients were not accidental, and the results were meaningful, so they can be used in further research works. To increase the reliability of the results obtained, it was decided to gradually increase the number of experts with the addition of 5 people to the survey at each subsequent stage.

After each stage of the survey with the addition of experts, the indicators W and χ^2 were determined. It has been found that with the increase in the number of experts, for the most part, the consensus of experts' opinions was mostly medium, and in some cases low, and by zones, the consensus was mostly low, sometimes medium. When the survey was conducted for 50 experts, there was an average consensus on the impact of risk factors in certain technological areas of the longwall, and on some factors–a high consistency. By technological zones, the results of calculations showed low agreement. These results were due to the fact that the experts had a more unambiguous opinion about the impact of each factor on the miner during the work but differed in the assessment of technological zones, since each expert had his own subjective opinion about the technological scheme in longwall. Thus the scientists considered the schemes on which their research was based, and the mine workers considered the schemes adopted at the enterprise. Further increase in the number of experts did not make sense, as W and χ^2 changed insignificantly (Table 2).

Table 2. Assessing consistency of experts' opinions depending on their number.

Numbers of technological zones		Values of concordance coefficients and Pearson's criteria																
		by factors									by zones							
											m = 20			m = 40		m = 50		
		Noise	Vibration	Lighting	Dustiness	Limitation	Clutter	Level of mechanization	Difficulty of work	Collapse of roof rocks	W	χ^2	...	W	χ^2	W	χ^2	χ^2_{table}
I		-	-	-	-	-	-	-	-	-	0.63	101	...	0.62	197.3	0.58	230.9	15.51
II		-	-	-	-	-	-	-	-	-	0.35	56.6	...	0.51	182.1	0.43	195.5	
III		-	-	-	-	-	-	-	-	-	0.32	51.3	...	0.36	113.6	0.31	123.5	
IV		-	-	-	-	-	-	-	-	-	0.38	60.4	...	0.42	134.4	0.40	160.5	
V		-	-	-	-	-	-	-	-	-	0.38	60.4	...	0.45	143.0	0.38	150.4	
VI		-	-	-	-	-	-	-	-	-	0.38	60.4	...	0.46	145.8	0.38	153.3	
VII		-	-	-	-	-	-	-	-	-	0.61	97.7	...	0.65	207.2	0.59	234.1	
VIII		-	-	-	-	-	-	-	-	-	0.18	29.4	...	0.31	100.5	0.31	122.4	
IX		-	-	-	-	-	-	-	-	-	0.36	57.0	...	0.42	135.8	0.35	141.3	
X		-	-	-	-	-	-	-	-	-	0.36	57.6	...	0.44	140.8	0.40	158.7	
m=7	W	0.74	0.67	0.53	0.76	0.52	0.66	0.40	0.54	0.43								
	χ^2	46.7	41.9	33.3	48.1	33.0	41.7	25.3	34.3	27.0								
m=15	W	0.68	0.64	0.42	0.65	0.57	0.57	0.33	0.61	0.43								
	χ^2	91.9	86.6	57.2	87.5	76.8	77.2	44.8	82.6	63.0								
m=20	W	0.65	0.61	0.43	0.64	0.57	0.52	0.35	0.69	0.43								
	χ^2	117.5	109.8	78.0	114.4	102.2	93.7	63.6	123.7	78.0								
m=30	W	0.68	0.68	0.45	0.69	0.63	0.59	0.45	0.74	0.49								
	χ^2	183.8	182.5	121.6	187.0	168.8	158.8	120.4	200.4	132.4								
m=40	W	0.68	0.72	0.51	0.75	0.68	0.62	0.56	0.77	0.56								
	χ^2	246.3	258.8	183.1	268.3	245.1	225.0	201.2	277.1	203.4								
m=45	W	0.68	0.65	0.50	0.74	0.63	0.60	0.58	0.75	0.51								
	χ^2	275.3	262.7	204.4	300.1	254.7	244.3	233.8	305.5	206.2								
m=50	W	0.65	0.60	0.50	0.74	0.58	0.55	0.56	0.75	0.51								
	χ^2	292.5	271.0	225.6	330.9	259.6	248.0	251.2	337.9	230.4								
χ^2_{table}		16.92									m – is the number of experts							

The consistency of experts' opinions on the concordance coefficient is assessed as:

low ($W < 0.5$);
medium ($0.5 \leq W < 0.7$);
high ($W \geq 0.7$).

When $\chi^2 > \chi^2_{table}$, the values of the corresponding coefficients W are not random. The obtained results make sense and can be used in further research.

The number of experts in the group of 50 has been accepted to assess the priority of factor consideration and regard of zones. According to the results of the survey, after calculating the concordance coefficients and Pearson's criteria, the sums of ranks obtained by factors and zones, and their share have been determined (Table 3). The biggest share corresponded to the most difficult working conditions of miners (the most important factor in the most dangerous technological zone), so those conditions were given the highest rating and priority for event planning. Less difficult conditions were given lower ratings depending on the share in the end.

Based on the calculations, the matrix of priority factors was taken into account and technological zones were considered for event planning (Table 4). In this matrix, according to the values of shares related to the relevant factor and zone, working conditions were additionally divided into three priority categories according to share ranges: high (a share is from 2.1% to 1.5%), medium (a share is from 1.4% to 0.8%) and low (a share is from 0.7% to 0%).

Table 3. Results of determining ratings of factors and technological zones by amounts of transformed ranks and indicators of importance.

Numbers of technological zones		Values of indicators by factors										
		Noise	**Vibration**	**Lighting**	**Dustiness**	**Limitation**	**Clutter**	**Level of mechanizatio**	**Difficulty of work**	**Collapse of roof rocks**	**Sums of ranks ands hares by zones**	Zone rating
I	ranks	91	54	50	99	82	87	35	11	78	**587**	IV
	share, %	2.0	1.2	1.1	2.2	1.8	1.9	0.8	0.2	1.7	**12.8**	
II	ranks	42	10	42	62	50	55	74	20	51	**406**	VI
	share, %	0.9	0.2	0.9	1.4	1.1	1.2	1.6	0.4	1.1	**8.9**	
III	ranks	26	4	6	15	41	38	10	14	34	**188**	VIII
	share, %	0.6	0.1	0.1	0.3	0.9	0.8	0.2	0.3	0.7	**4.1**	
IV	ranks	84	52	48	93	87	86	83	89	89	**711**	III
	share, %	1.8	1.1	1.0	2.0	1.9	1.9	1.8	1.9	1.9	**15.5**	
V	ranks	85	83	45	92	86	82	83	96	90	**742**	II
	share, %	1.9	1.8	1.0	2.0	1.9	1.8	1.8	2.1	2.0	**16.2**	
VI	ranks	87	78	47	92	87	87	82	95	90	**745**	I
	share, %	1.9	1.7	1.0	2.0	1.9	1.9	1.8	2.1	2.0	**16.3**	
VII	ranks	43	13	38	52	79	52	16	89	88	**470**	V
	share, %	0.9	0.3	0.8	1.1	1.7	1.1	0.3	1.9	1.9	**10.3**	
VIII	ranks	49	14	45	56	42	47	43	59	49	**404**	VII
	share, %	1.1	0.3	1.0	1.2	0.9	1.0	0.9	1.3	1.1	**8.8**	
IX	ranks	11	11	7	12	10	19	8	51	15	**144**	X
	share, %	0.2	0.2	0.2	0.3	0.2	0.4	0.2	1.1	0.3	**3.1**	
X	ranks	9	2	35	14	14	14	13	54	25	**180**	IX
	share, %	0.2	0.0	0.8	0.3	0.3	0.3	0.3	1.2	0.5	**3.9**	
Sums of ranks by zones		**527**	**321**	**363**	**587**	**578**	**567**	**447**	**578**	**609**	**4577**	
Sums of shares by factors, %		**11.5**	**7.0**	**7.9**	**12.8**	**12.6**	**12.4**	**9.8**	**12.6**	**13.3**	**100**	
Factor rating		V	VIII	VII	II	III	IV	VI	III	I		

According to the constructed matrix, it is possible to determine the most important conditions that need to be given priority. The most responsible zones in the planning of activities taking into account the working conditions of miners are the ones that are in the end sections of the longwalls (zones IV, V, VI). They are followed by the area where the coal shearer works (zone I), the construction of protection means (zone VII), and the connection of the longwall with the roadways (zone VIII). The lowest priority is given to zones III, IX, and X. The highest priority is given to such factors as the collapse of roof rocks, dustiness and clutter of the working space, and the difficulty of operations. Vibration and lighting of the working space are given the lowest priority.

Noise and vibration levels can be reduced when modern equipment is used. However, it is not always possible to completely eliminate these factors or reduce them to acceptable values because their main sources are running engines and moving parts. You can reduce the impact of noise on the miner if he works in earplugs, helmets or protective headphones. To reduce the impact of vibration on a person, it is necessary to avoid direct contact with the source of vibration due to special equipment or organization of work so that the miners performing their duties stay as little as possible in the danger zone. Particular attention should be paid to the influence of these factors in the end sections of longwalls (zones IV, V, VI), connections of roadways (zone VIII), and near the coal shearers (zone I).

Table 4. Priority matrix of factor consideration and consideration of technological zones of longwalls for planning occupational safety measures.

Numbers of technological zones	Importance of the relevant factors in the final assessment to determine the priority of their consideration for action planning, %									Zone priority assessment	
	Collapse of roof rocks	Dustiness	Limitation	Difficulty of work	Clutter	Noise	Level of mechanization	Lighting	Vibration	Total share by zones, %	Zone rating
VI	2.0	2.0	1.9	2.1	1.9	1.9	1.8	1.0	1.7	16.3	I
V	2.0	2.0	1.9	2.1	1.8	1.9	1.8	1.0	1.8	16.2	II
IV	1.9	2.0	1.9	1.9	1.9	1.8	1.8	1.0	1.1	15.5	III
I	1.7	2.2	1.8	0.2	1.9	2.0	0.8	1.1	1.2	12.8	IV
VII	1.9	1.1	1.7	1.9	1.1	0.9	0.3	0.8	0.3	10.3	V
II	1.1	1.4	1.1	0.4	1.2	0.9	1.6	0.9	0.2	8.9	VI
VIII	1.1	1.2	0.9	1.3	1.0	1.1	0.9	1.0	0.3	8.8	VII
III	0.7	0.3	0.9	0.3	0.8	0.6	0.2	0.1	0.1	4.1	VIII
X	0.5	0.3	0.3	1.2	0.3	0.2	0.3	0.8	0	3.9	IX
IX	0.3	0.3	0.2	1.1	0.4	0.2	0.2	0.2	0.2	3.1	X
Total share by zones, %	13.3	12.8	12.6	12.6	12.4	11.5	9.8	7.9	7.0		
Priority factor	I	II	III	III	IV	V	VI	VII	VIII		

*color indicates factors and zones that are divided into 3 categories: ■ – high priority; □ – medium priority; □ – low priority.

To prevent dustiness in the technological zones of the longwalls, it is recommended to use efficient irrigation systems when removing niches (zones IV, V, VI) and when the coal shearers operate (zone I), as well as effective ventilation of workplaces with fresh.

In technological zones, it is expedient to provide stationary lighting. All these measures are known to designers [70, 71].

A limited and cluttered workspace is determined by mining and geological conditions, parameters of the means of barring and mechanization of work, as well as the discipline of keeping the workplace in good condition. In zones with the smallest areas of working space and with the greatest clutter, it is necessary to use non-bulky barring, equipment, tools, etc. It is advisable to design workplaces taking into account the anthropometric characteristics of miners. As a rule, these are zones II, IV, V, VI, VII.

To increase the level of mechanization of works it is necessary to start working without niches and use mechanized means of barring in all technological zones of the longwall. First of all, it is necessary to reduce the share of manual labor in zones IV-VII, IX, and X. Increasing the level of mechanization of work will reduce the difficulty of work during operations. However, in some cases, mechanization and automation of work lead to intensification of production and additional loads on the miners, so the marker indicator of the level of mechanization of work should take the energy expenditure of the miners. This indicator should be taken into account when performing operations with a low level of mechanization. The results of the calculation of energy consumption should be the development of schedules for the organization of work with the optimal mode of their implementation and planning of regulated breaks for compensatory rest for an hour. Such breaks are necessary for operations with an energy value exceeding 290 W [52]. These include: control of barring sections (zone II); extraction of coal in niches with jackhammers and its loading, barring of niches (IV, V, VI); construction of protection means (VII); moving of elements of the arch bar, taking out the rock mass, setting of barring (VIII-X). For making up schedules of the organization of works, it is expedient to apply a technique of determining the difficulty of miners' work and the duration of compensatory breaks in their working process.

Performing energy-consuming work in the end sections of longwalls in conditions of limited and cluttered working space, noise, dust, and limited lighting does not allow the miner to fully assess the environment and control the rock mass to avoid injury from its collapse. The collapse of roof rocks is given high priority in the area of operation of the combine (zone I) and the final sections of longwalls (zones IV, V, VI). In these zones, the operations are performed in conditions of intensive deformation of roof rocks. The Safety Rules for Miners regulate prevention of lagging of the barring sections from the combine as far as 6 m, presence of the worker under the protection of the walling, control of the safe condition of the workplace, etc.

4. Conclusions

This work was based on the expert surveys of labor protection specialists in the coal mines of Ukraine. According to the results of the work, the importance of taking into account risk factors when planning labor protection measures in some technological zones of the longwall when applying the technology of coal mining with long pillars has been proven. It has also been substantiated that when developing and applying measures to prevent injuries, it is necessary to take into account the psycho-physiological, mining-technical, and mining-geological factors that determine the working conditions of miners. Among these factors, the priority of consideration has been established, especially in different technological zones of longwalls, where they have different effects on the safety of miners. This has been proven by the survey results. Until now, risk factors have mostly been considered for a longwall in general without dividing it into separate zones. This fact emphasizes the scientific novelty of the research work.

Based on the results of statistical processing of 50 experts survey, a matrix for assessing the priority of taking into account masking, distracting and dangerous factors, namely: collapse of roof rocks, dustiness, limitation, difficulty of work, clutter, noise, level of mechanization, lighting, vibration, has been developed. Technological zones of a longwall have also been ranked for planning labor protection measures. The most responsible areas when planning such measures, taking into account the working conditions of miners and risk factors, have been determined the zone of operation of a shearer and the zones in the end sections of a longwall. They are followed by the zones for construction of protection means and the zones which joint the longwall with the workings. It has been established that the highest priority in planning measures for labor protection should belong to: the collapse of roof rocks, dustiness and clutter of the working space, and the difficulty of performing operations.

This matrix can be used in the planning of labor protection measures and the design of mining operations in the case of underground coal mining with long pillars, when the coal seams have a thickness up to 2.5 m and with a dip angle of up to 24^o. For other parameters, it is necessary to carry out additional research with the involvement of experts in the field of mineral mining in certain conditions.

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چکیده:

مطالعه‌ی عوامل خطر که ایمنی معدنچیان به آنها بستگی دارد مرتبط است. این عوامل شامل دما و سرعت هوا در جاده ها، رطوبت نسبی هوا، گرد و غبار، صدا و لرزش، روشنایی، بهم ریختگی و وجود صداهای ناهنجار، فضای کاری محدود، سختی کار و ریزش سنگ‌های سقف می‌باشد. بیشترین تمرکز آنها در مناطق تکنولوژیکی جبهه‌کار طولانی است، بنابراین تعیین اولویت در نظر گرفتن عوامل خطر در مناطق خاص برای برنامه ریزی اقدامات برای حفاظت از نیروی کار در معدن زغالسنگ زیرزمینی مهم است. بنابراین، ماتریس اولویت عوامل خطر برای روش معدنکاری جبهه‌کار طولانی در منطقه تکنولوژیکی پیشنهاد شده است. ماتریس بر اساس نظرسنجی از دانشمندان و مهندسان با تجربه و آگاه معادن زغالسنگ (متخصصان) تعریف شده است. پنجاه کارشناس در این نظرسنجی شرکت کردند. ماتریس اولویت عوامل خطر را ارزیابی می‌کند و مناطق فنآوری جبهه‌کار طولانی را برای برنامه ریزی اقدامات حفاظت از کار در نظر می‌گیرد. مناطق عملیاتی ماشین‌های حفاری و بخش‌های انتهایی جبهه‌کار طولانی به‌عنوان بحرانی‌ترین مناطق ایمنی تعریف می‌شوند. مناطق حفاظتی و نواحی اتصال جبهه‌کار طولانی با معابر از اهمیت کمتری برخوردارند، اما در عین حال خطرناک هستند. سطح یک عامل خطر خاص برای هر منطقه تعیین می‌شود. بیشترین اولویت را باید به ریزش سقف‌ها، گرد و غبار، به هم ریختگی فضای کار و شدت کار معدنچیان داد. برای هر یک از عوامل خطر موجود در ماتریس، اقدامات فنی و سازمانی برای حفاظت از نیروی کار برای کاهش سطح صدمات برای معدنچیان پیشنهاد شده است.

کلمات کلیدی: عامل خطر، زون جبهه‌کار طولانی، نظرسنجی کارشناسان، ماتریس اولویت، اقدامات حفاظت از نیروی کار.