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Identifying the mining enterprise units with a significant level of non-compliance with occupational safety requirements using the example of a coal mine

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Abstract

Purpose. The research aims to develop a process for identifying mining enterprise units with a significant level of non-compliance with occupational safety and health requirements of employees using the Grey Relational Analysis method.

Methods. To identify the units of a mining enterprise with a significant level of non-compliance with occupational safety and health requirements of employees, the Grey Relational Analysis method is used, which allows ranking the mining enterprise units according to actual and target (reference) indicators.

Findings. A nine-step process has been developed for identifying mining enterprise units with a significant level of non-compliance with occupational safety and health requirements of employees using the Grey Relational Analysis method. A checklist for internal audit of units on compliance with occupational safety and health requirements of miners is proposed, which allows determining the coefficient of non-compliance with occupational safety and health requirements of miners in accordance with ISO 45001:2018 standard, as the ratio of positive and negative responses of auditors. Based on the results of calculating the numerical values of compliance with occupational safety and health requirements of miners, it has been determined that the worst coefficient of non-compliance, which is more than 20%, is at the sites of conveyor transport and assembling / disassembling operations. It is proposed to determine the materiality criterion of non-compliance with occupational safety and health requirements of employees as the difference between the reference and current level of compliance with occupational safety and health requirements of employees.

Originality. The scientific novelty of the research is to identify the relationship between the coefficient of compliance (non-compliance) with occupational safety and health requirements and the materiality criterion of non-compliance, which characterize the attitude of miners to occupational safety requirements.

Practical implications. A process has been developed to identify mining enterprise units with significant non-compliance with occupational safety and health requirements of employees, which allows for the introduction of appropriate precautionary and protective measures to reduce occupational risks.

Keywords: *unit, mining enterprise, occupational safety, employees' health, occupational safety and health requirements of employees*

1. Relevance of the research

A common problem at many mining enterprises is the formal attitude to the implementation of occupational safety and health (OSH) requirements of employees [1]. The main symptoms are that standards are "dead" documents, briefings are conducted on formal grounds, rules are observed only in the presence of supervisory bodies, and managers themselves neglect to comply with the basic OSH requirements. The answer to the question of why this happens is not only in the area of employees' personal attitude towards occupational safety, but also in the level of safety culture organization. Inadequate personal attitude to the organization of a safe production process arises from a lack of awareness of the level of surrounding dangers [2], [3]. It is also due to the lack of sufficient knowledge and skills, that is, low competence in performing production tasks in high-quality and safe manner. Unfortunately, the occupational safety rules that employees know in most cases are ignored because of their unique worldview, and these rules are often associated with burdensome unnecessary waste of time. Given that violations of OSH requirements do not always lead to injury [4], employees eventually become convinced that they are right. This increases confidence in their decisions and increases the probability of dangerous event occurrence due to dangerous actions [5]. This raises the urgent task of searching for ways to change the attitude of employees to OSH requirements [6],

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[7]. In this case, the first step to solving it is to identify the problem: to determine the actual state of compliance with OSH requirements at each workplace and in each unit of the mining enterprise [8]. The data found are primarily needed to clarify the impact of dangerous factors (human, organizational) on the level of occupational hazard risk. For example, when calculating the residual level of occupational risk after selecting and substantiating various protective and precautionary measures, for some reason, by default, it is considered to be undeniable their implementation and execution [9], [10]. At the same time, the algorithm for calculating the residual value of occupational risk does not provide for the fact that the implementation of precautionary and protective measures will be partial, that employees will ignore the observance of certain obligations imposed on them. Hence, the level of real occupational risk may differ significantly from the estimated one, which requires appropriate clarification, experimental verification or introduction of certain coefficients that will characterize the attitude of employees to complying with OSH requirements, thereby leading to real occupational risk assessments. As a result, there is a need to develop a process for identifying mining enterprise units with a significant level of non-compliance with OSH requirements, which will further clarify the level of occupational risk, as well as develop recommendations for changing the attitude of employees to OSH requirements.

2. Analysis of recent research and publications

Significant attention is paid to improving the level of occupational safety and health of employees, especially in coal mines. Existing studies show that inadequate application and implementation of occupational safety and health measures for employees impair social and economic growth [2], [11]. For example, in [12], the authors show a correlation between employee health/safety and company profit growth through a study of their market performance. The authors suggest the existence of the hypothesis that reducing risks to employee health and safety leads to an increase in company's shares. To prove it, the activity of the stock market was analyzed, to identify the most significant factors that increase the investment attractiveness of organizations, which allowed to confirm the above hypothesis.

To properly implement various occupational safety and health measures for employees, as well as to balance financial costs, organizations implement safety management systems. Its main processes include hazard identification, planning of safety measures, effective implementation and analysis of occupational risks to reduce the probability of accidents occurring at the workplace [13], [14]. Occupational safety management processes also include the formation of policies, strategies, practices and procedures that are implemented to prevent employee injuries. In this case, one of the most important procedures is the organization of proper on-the-job training for miners on occupational safety issues and the analysis of accidents at the workplace, as this helps to change the attitude of employees towards occupational safety [15]. Existing studies show that in order to reduce human errors and accidents at the workplace [16], [17], it is necessary for the organization's management to promote the development of a safety culture, leadership institutions, and communication based on mutual support, assistance, and respect between employees. In addition, the authors of the research indicate that compliance with safety rules is itself formed through culture. Otherwise, there is a destruction of any positive changes in the organization. By the way, the conclusions of the above-mentioned study emphasize that employee errors arising from non-compliance with safety requirements or deliberate violation of them are the dominant factor in accidents, which emphasizes the importance of observing safety protocols to reduce the number of accidents at workplaces [18]. Similar conclusions are made in the following study [19]. The authors note that safety leaders can play an important role in stopping negative practices that can lead to injuries or accidents.

It is interesting that some experts emphasize [20] that appropriate training can change attitudes toward compliance with occupational safety requirements. Therefore, it is necessary to develop appropriate training programs based on the task of forming a positive attitude towards fulfilling occupational safety requirements. At the same time, there are studies that point to the need for a comprehensive approach to forming a conscious attitude towards occupational safety. For example, in [21], the authors analyzed data on accidents at coal enterprises over 14 years and found that hazard identification is a key process in the occupational safety management system, but to reduce injuries, it is necessary to clearly convey information to employees. If the information is not clear and accessible, other processes in the organization will not be executed, no matter how organized they are. Methods such as "what-if" analysis and "event tree", bow-tie model are often used to identify hazards and predict the development of events in advance [22]. At the same time, when implementing appropriate precautionary measures, their complexity is often not taken into account, which leads to their ignoring or failure to implement or apply them to actually reduce the risk [23]. In [24], it is stated that it is necessary to involve employees in strategic decisions in occupational safety management systems, which can significantly reduce the level of occupational injuries and accidents. Involvement of employees causes a change in their attitude to the implementation of safety measures, and most importantly, it helps to report the causes of accidents at the workplace to managers without fear of being punished [25]. Employees' independent decisions, selection and implementation of precautionary measures significantly increase both safety awareness and the desire to comply with their own self-developed requirements or rules for handling technologies, machines or mechanisms. Similarly, the participation of employees in the development of the organization's safety policy creates conditions for their loyal attitude towards fulfilling the occupational safety and health requirements of miners [26]. In [27], the authors have developed a database of hazards with the following groups: rock movement, rope transport, conveyors, dump trucks, electricity, dust and gas, flooding, etc., which allowed them to identify which dangerous factors increase the probability of a dangerous event occurrence. It should be noted that to ensure the objectivity of the analysis results, the authors visited the coal mine and observed the actions or lack of actions of the miners. This made it possible to draw conclusions about the causes of injuries, including both objective and subjective ones. The latter, according to the authors, are the main ones, since they most lead to injuries. To reduce them, it is necessary to develop clear instructions and increase control over their implementation or compliance. An interesting work is presented by the authors in [28], who propose software for risk prevention and safety management in coal mines. The software product provides a user-friendly interface that makes it easy to use various functions: statistical analysis of data on hazards, risks and accidents, dynamic monitoring of hazards and risks, as well as a module that helps to analyze the effectiveness of managerial decisions taken to prevent possible consequences. It is based on comparing the financial costs of various alternative occupational safety precautions. The authors covered a wide range of OSH management methods, analyzed the scientific literature on these issues and received positive feedback from OSH experts in coal mines, but did not take into account that, in addition to financial costs, the effectiveness of solutions depends on their degree of implementation. The study [29] aims to analyze occupational diseases of workers at coal enterprises. For this purpose, a risk assessment model was developed and the risk of developing occupational diseases was simulated. The risk assessment model includes the following factors: age, gender, work experience, working conditions and health status. The study distinguished the most common occupational diseases among coal mine workers: silicosis, chronic obstructive bronchitis, pneumoconiosis, and vibration disease. The most significant risk factors for the development of occupational diseases are: work experience, working conditions and health status, as well as compliance with the requirements for the proper use of personal protective equipment. The authors propose the following recommendations: improving the ventilation of mine workings, using personal protective equipment, regular and high-quality medical examinations, training and informing employees about the risks of occupational diseases and methods of their prevention. The analyzed papers describe various aspects of the OSH management systems, including hazard identification, risk management methods, risk control technologies, risk assessment of developing occupational diseases, the process of training miners on occupational safety issues and their involvement in making managerial decisions in the field of occupational safety. At the same time, the above algorithms for solving the tasks do not allow assessing the overall risk of hazards in coal mines, taking into account the non-compliance with OSH requirements by employees at their workplaces. However, this would make it possible to obtain predictive injury rates at specific production sites of a mining enterprise and to propose timely precautionary measures to avoid the development of worst-case scenarios of dangerous situations.

The purpose of the paper is to develop a process for determining the mining enterprise units with a significant level of non-compliance with OSH requirements using the Grey Relational Analysis method.

3. Research methods

There are a large number of methods that allow for a comprehensive assessment of the OSH level at mining enterprises. The Occupational Safety and Health Management System (OSHMS) is an example of a "grey" system, as it is partly known and partly unknown. In theory, Grey Relational Analysis helps to find the relationship between objects – the mining enterprise units – and their characteristics – the performance indicators of these mining enterprise units. When comparing, the reference sequence (indicators that are planned and are target) is correlated with the compared sequences (indicators that are actual and current) that show a certain degree of similarity to the reference indicators, and thus, the best of them is determined.

Therefore, it is proposed to base the process for determining the mining enterprise units with a significant level of non-compliance with OSH requirements, which is shown in Figure 1, on the relationship between the coefficient of compliance (non-compliance) with OSH requirements of employees and the criterion of the materiality of non-compliance with OSH requirements.

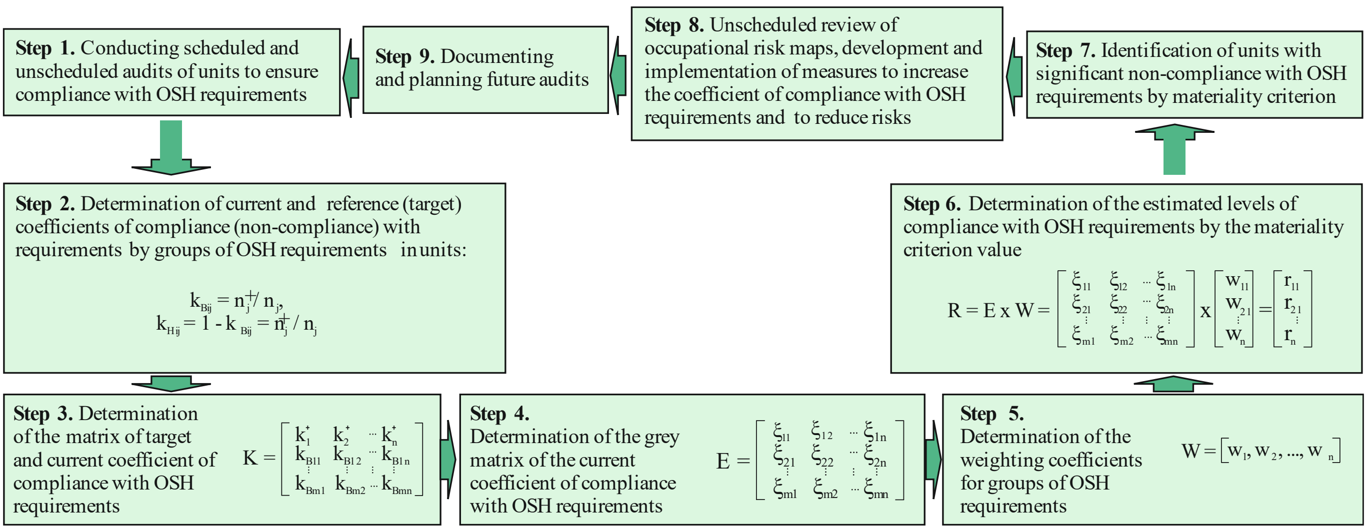

Figure 1. The process of identifying mining enterprise units where there is a significant level of non-compliance with the requirements using the Grey Relational Analysis method

In the first step, the OSH audits are conducted to determine compliance with the requirements, using the developed checklists (Table 1).

Next, in the second step, the coefficient of compliance with OSH requirements is calculated using the Formula:

$$k_{Bij} = n_j^+ / n_j ;$$
$$k_{Hij} = 1 - k_{Bij} = n_j^+ / n_j , \tag{1}$$

where:

n_j^+ – the number of requirements fulfilled (as determined from audit, supervision or self-assessment reports);

n_j^- – the number of requirements unfulfilled (as determined from audit, supervision or self-assessment reports);

n_j – total number of OSH requirements of the j-unit (or document).

Then, a set of reference (target) indicators is defined, which are displayed as a series of $K^* = [k_1^*\ k_2^*\ \cdots\ k_n^*]$. In the third step, based on the collected information on the state of non-compliance (compliance) with OSH requirements in m mining enterprise units, according to the determined n non-compliance (compliance) coefficients by employees according to groups of OSH requirements, it is possible to compile a matrix to determine the attitude to the compliance with OSH requirements by the mining enterprise units [30]:

$$K = \begin{bmatrix} k_1^* & k_2^* & \cdots & k_n^* \\ k_{B11} & k_{B12} & \cdots & k_{B1n} \\ \vdots & \vdots & \vdots & \vdots \\ k_{Bm1} & k_{Bm2} & \cdots & k_{Bmn} \end{bmatrix}, \tag{2}$$

where:

k_{Bij} – j-th coefficient of compliance with the requirements for the i-th section of the requirements (the relevant document of OSH requirements); series of $K = [K_1, K_2, \cdots, K_n]$ – characterizes the reference coefficients of compliance with OSH requirements.

In the fourth step, using a set of coefficients of compliance with OSH requirements K^* of the reference sequence (determined by the planned target indicator) and the matrix K of the compared sequence, the grey relation of the j-th assessment indicator – the coefficient of compliance with the requirements in the i-th mining enterprise unit – was obtained by the Formula [30]:

$$\xi_{ij} = \frac{\min\limits_{\substack{1\le i\le m \\ 1\le j\le n}} \left| k_j^* - k_{Bij} \right| + \rho \max\limits_{\substack{1\le i\le m \\ 1\le j\le n}} \left| k_j^* - k_{Bij} \right|}{\left| k_j^* - k_{Bij} \right| + \rho \max\limits_{\substack{1\le i\le m \\ 1\le j\le n}} \left| k_j^* - k_{Bij} \right|} ; \tag{3}$$

$$E = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \xi_{m1} & \xi_{m2} & \cdots & \xi_{mn} \end{bmatrix}. \tag{4}$$

In the fifth step, the weighting coefficients are determined according to the groups of requirements, from which a matrix is formed:

$$W = \left[w_1, w_2, \ldots, w_n \right]. \tag{5}$$

The weighting factors between the groups of OSH requirements are determined by experts using a scale from 0 to 1, where 0 means no influence. Requirements for experts are given in Table 2.

The Grubbs' Test was applied to process the results provided by the experts and verify their estimates of outliers [31]:

$$G_{\max} = \frac{w_n - \bar{w}}{S}, \tag{6}$$

where:

w_n – proposed expert assessments;

$\bar{w}$ – average sample value;

S – mean square deviation.

Where it is necessary to calculate the mathematical expectation or the average value of the results obtained:

$$\bar{w} = \frac{1}{n} \sum_{i=1}^{n} w_i . \tag{7}$$

It is also necessary to calculate the mean square deviation:

$$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(w_i - \bar{w} \right)^2} . \tag{8}$$

Using the above formulas, we check the maximum and minimum results of expert assessments for outliers, provided that the indicator exceeds the critical value:

$$\begin{cases} G_{\max} \ge G_{n,\ 1-\alpha} \\ G_{\min} \ge G_{1,\ 1-\alpha} \end{cases}, \tag{9}$$

where:

α – the level of materiality, which is determined in accordance with the requirements of ISO 5725-2:2005 standard "Accuracy (trueness and precision) of measurement methods and results Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method" [32].

In case of failure to comply with this inequality, the results of the assessments will be considered outliers, which need to be excluded. Moreover, the experts who gave such an assessment are explained to identify the reasons for the validity of their choice of scores during the examination. Critical values of statistics are selected based on the law of random variable distribution. These values can be found for a normal distribution according to the requirements [32].

In the sixth step, the grey relation between the levels of OSH at production sites is calculated using the Formula 4:

$$R = E \times W = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \xi_{m1} & \xi_{m2} & \cdots & \xi_{mn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{bmatrix}. \tag{10}$$

The higher the degree of grey relation r_i, the closer the i-th assessment of the indicators of compliance with OSH requirements is to the set of indices K^*. Accordingly, the order, that is, the ranking of the assessed mining enterprise units was determined.

In the seventh step, the significant level of non-compliance with the requirements is determined based on the calculated sum of percentages not exceeding 30% by the determined grey relation value of the coefficient of compliance with OSH requirements per unit from a lower value to a higher one [32]. In the eighth step, the occupational risk maps are reviewed to substantiate and implement measures to improve compliance with OSH requirements. In the ninth step, a plan is formed for the following inspections of compliance with OSH requirements in units, with verification of the effectiveness of the proposed measures.

Table 1. A fragment of the internal audit checklist for determining the coefficient of compliance with OSH requirements at the site in accordance with ISO 45001:2018 standard

No.	The requirements are defined in OSHMS of the mining enterprise, which comply with ISO 45001:2019 standard	Designation of the requirement	Fulfillment of requirements		Notes
			Yes "+"	No "–"	
	Group 1. Requirements for analyzing the organization's environment (i = 1) (1 – number of the requirement group of the section 4, j – number of the requirement in group 1 of the section 4 requirements)				
1	Are external and internal factors identified at the workplace that influence the ability to achieve the planned result?	B_{11}	+		
j		B_{ij}	…	…	
n_1	…	B_{1n1}	…	…	
	Total requirements:	$n_1 = n_1^+ + n_1^-$	n_1^+	n_1^-	
	Coefficient of compliance with requirements:	$K_{B1} = n_1^+ / n_1$	K_{B1}		
	Coefficient of non-compliance with requirements:	$K_{n1} = n_1^- / n_1$		K_{n1}	
	Group 2. Requirements for OSHMS leadership (i = 2) (2 – number of the requirement group of the section 5, j – number of the requirement in group 2 of the section 5 requirements)				
1	Do managers discuss issues related to improving OSH level with employees?	B_{21}	+	…	
j	…	B_{ij}	…	…	
n_2	…	B_{2n2}	…	…	
	Total requirements:	$n_2 = n_2^+ + n_2^-$	n_2^+	n_2^-	
	Coefficient of compliance with requirements:	$K_{B2} = n_2^+ / n_2$	K_{B2}		
	Coefficient of non-compliance with requirements:	$K_{n2} = n_2^- / n_2$		K_{n2}	
	Group 3. Requirements for OSHMS planning (i = 3) (3 – number of the requirement group of the section 6, j – number of the requirement in group 3 of the section 6 requirements)				
1	Are risks and opportunities identified for OSHMS and its planned outcomes?	B_{31}	+	…	
j	…	B_{ij}	…	…	
n_3	…	B_{3n3}	…	…	
	Total requirements:	$n_3 = n_3^+ + n_3^-$	n_3^+	n_3^-	
	Coefficient of compliance with requirements:	$K_{B3} = n_3^+ / n_3$	K_{B3}		
	Coefficient of non-compliance with requirements:	$K_{n3} = n_3^- / n_3$		K_{n3}	
	Group 4. Requirements for OSHMS functioning (i = 4) (4 – number of the requirement group of the section 7, j – number of the requirement in group 4 of the section 7 requirements)				
1	Does the unit plan and implement processes to ensure compliance with OSH requirements?	B_{41}	+	….	
j	…	B_{ij}	…	…	
n_4	…	B_{4n4}	…	…	
	Total requirements:	$n_4 = n_4^+ + n_4^-$	n_4^+	n_4^-	
	Coefficient of compliance with requirements:	$K_{B4} = n_4^+ / n_4$	K_{B4}		
	Coefficient of non-compliance with requirements:	$K_{n4} = n_4^- / n_4$		K_{n4}	
	Group 5. Requirements for OSHMS effectiveness (i = 5) (5 – number of the requirement group of the section 8, j – number of the requirement in group 5 of the section 8 requirements)				
1	Has a procedure been developed for monitoring, measuring, analyzing and assessing the effectiveness of production equipment safety systems?	B_{51}	+		
2	Are legal and other requirements complied with when assessing the effectiveness of production equipment safety systems?	B_{52}	+		
j	…	B_{ij}	…	…	
n_5	…	B_{5n5}	…	…	
	Total requirements:	$n_5 = n_5^+ + n_5^-$	n_5^+	n_5^-	
	Coefficient of compliance with requirements:	$K_{B5} = n_5^+ / n_5$	K_{B5}		
	Coefficient of non-compliance with requirements:	$K_{n5} = n_5^- / n_5$		K_{n5}	
	Group 6. Requirements for OSHMS ensuring (i = 6) (6 – number of the requirement group of the section 9, j – number of the requirement in group 6 of the section 9 requirements)				
1	Does the unit identify and provide the resources necessary to develop, implement, maintain and continuously improve OSHMS?	B_{61}			
2	Are employees aware of the OHS policy and objectives?	B_{62}			
j	…	B_{ij}	…	…	
n_6	…	B_{6n6}	…	…	
	Total requirements:	$n_6 = n_6^+ + n_6^-$	n_6^+	n_6^-	
	Coefficient of compliance with requirements:	$K_{B6} = n_6^+ / n_6$	K_{B6}		
	Coefficient of non-compliance with requirements:	$K_{n6} = n_6^- / n_6$		K_{n6}	
	Group 7. Requirements for OSHMS improvement (i = 7) (7 – number of the requirement group of the section 10, j – number of the requirement in group 7 of the section 10 requirements)				
1	Does the unit identify opportunities to improve OSHMS?	B_{71}	+		
2	Has the unit developed, implemented and maintained processes to identify and manage incidents and non-conformities?	B_{72}	+		
j	…	B_{ij}	…	…	
n_7	…	B_{7n7}	…	…	
	Total requirements:	$n_7 = n_7^+ + n_7^-$	n_7^+	n_7^-	
	Coefficient of compliance with requirements:	$K_{B7} = n_7^+ / n_7$	K_{B7}	–	
	Coefficient of non-compliance with requirements:	$K_{n7} = n_7^- / n_7$	–	K_{n7}	

Table 2. Requirements for experts involved in determining weighting coefficients

Data	Number
Number of experts	Not less than 5
Work experience in positions	from 10 to 14 years
Education of experts	higher education in the specialty
Length of work experience	over 10 years
Availability of auditor's certificate for company quality and safety management systems	Yes
Advanced training in risk assessment as required [31]	Yes

4. Results and discussion

The calculation of determining the production units of a mining enterprise with a significant level of non-compliance with OSH requirements in accordance with the requirements of sections 4-10 in ISO 45001:2018 standard, using the Grey Relational Analysis method, was made on the example of a coal mine, where seven main production sites were examined (Table 3).

At the preparatory stage, all available information on the description of work performed at production sites, the list of hazards and existing precautionary and protective measures was analyzed, as well as a list of requirements that must be fulfilled to avoid injuries to employees was formed. The first and second steps resulted in the determination of the coefficients of non-compliance (compliance) with OSH requirements at the specified sites of the mine. The data obtained are presented in Table 4.

Table 3. Description of work performance and occupational hazards at coal mine sites

No.	Site	Description of the work performed	List of occupational hazards
1	Coal mining	Extraction of coal from the seam and loading it onto the conveyor	Rock falls; sudden outburst of coal and gas; methane ignition; coal dust explosion; injuries from moving machinery and hand tools; dust pollution of mine atmosphere; electric shock; vibration; noise
2	Preparatory operations	Creating new mine workings, their supporting and laying communications	Rock falls; sudden outburst of coal and gas; methane ignition; coal dust explosion; injuries from moving machinery and hand tools; dust pollution of mine atmosphere; electric shock; vibration; noise
3	Mine transport	Transportation of rock mass, people, equipment and materials through the mine using locomotives, trolleys, etc. Maintenance of railroad tracks and electrical equipment in proper condition	Rope breakage; vehicle collisions; vehicle derailment from the railroad track; electric shock; noise
4	Conveyor transport	Transportation of rock mass using conveyors. Maintenance of conveyors, cleaning and repair of conveyor belts	Clamping limbs between conveyor elements; belt breaks; electric shock; air pollution with dust
5	Repair of mine workings	Repairing and maintaining mine workings in a passportable condition, strengthening rocks, and filling fractures	Rock falls; injuries from hand tools; air pollution with dust; noise; vibration
6	Repair of face equipment	Ensuring trouble-free, high-performance operation of face equipment; scheduled repairs and inspections in accordance with the schedule	Injuries from moving parts of machines and mechanisms; electric shock; poisoning by technical fluids; noise
7	Assembling / disassembling operations	Assembling and disassembling equipment, fixtures, and pipelines	Injuries from falling objects; injuries from hoisting and transport mechanisms

Table 4. Results of determining the coefficients of compliance with occupational safety requirements according to the ISO 4500:2018 standard groups of requirements at each site

Mine sites	Reference coefficients of compliance with OSH requirements according to the ISO 4500:2018 standard groups of requirements						
	Section 4. Organization's environment	Section 5. Leadership	Section 6. Planning	Section 7. Ensuring	Section 8. Functioning	Section 9. Effectiveness	Section 10. Improvement
	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	The determined coefficients of compliance with OSH requirements by the ISO 4500:2018 standard groups of requirements						
Coal mining	0.88	0.86	0.89	0.90	0.76	0.56	0.45
Preparatory operations	0.60	0.86	0.79	0.73	0.86	0.78	0.59
Mine transport	0.64	0.78	0.48	0.68	0.57	0.65	0.79
Conveyor transport	0.80	0.90	0.84	0.93	0.98	0.99	0.97
Repair of mine workings	0.68	0.48	0.57	0.83	0.69	0.76	0.81
Repair of face equipment	0.90	0.93	0.95	0.70	0.86	0.84	0.90
Assembling / disassembling operations	0.80	0.90	0.84	0.93	0.98	0.99	0.97

$$K=\begin{bmatrix}1.00&1.00&1.00&1.00&1.00&1.00&1.00\\0.88&0.86&0.89&0.90&0.76&0.56&0.45\\0.60&0.86&0.79&0.73&0.86&0.78&0.59\\0.64&0.78&0.48&0.68&0.57&0.65&0.79\\0.80&0.90&0.84&0.93&0.98&0.99&0.97\\0.68&0.48&0.57&0.83&0.69&0.76&0.81\\0.90&0.93&0.95&0.70&0.86&0.84&0.90\\0.80&0.90&0.84&0.93&0.98&0.99&0.97\end{bmatrix}.$$

Based on them, we calculate the ratio of compliance with OSH requirements for the mine's production sites. In this case, to form the matrix, we take 100% compliance with OSH requirements for each section of the ISO 45001 standard, then the reference indicators of the OSH compliance coefficient will be as follows K^* = [1.00; 1.00; 1.00; 1.00; 1.00; 1.00; 1.00]. This makes it possible to obtain a general matrix of coefficients of compliance with OSH requirements.

Next, using Formula (3), the grey relation coefficients of compliance with OSH requirements are calculated:

$$E=\begin{bmatrix}0.36&0.32&0.38&0.40&0.22&0.13&0.11\\0.14&0.32&0.24&0.20&0.32&0.24&0.14\\0.16&0.23&0.11&0.17&0.13&0.16&0.24\\0.25&0.40&0.30&0.49&0.77&0.87&0.69\\0.17&0.11&0.13&0.28&0.18&0.23&0.26\\0.40&0.49&0.57&0.18&0.32&0.30&0.40\\0.25&0.40&0.30&0.49&0.77&0.87&0.69\end{bmatrix}.$$

To continue with the calculation, it is necessary to determine the weighting factors using expert analysis, which will indicate the groups of requirements that have the greatest influence on the probability of a dangerous event occurrence and the degrees of its severity. The results of calculating the weighting coefficients are presented in Table 5.

Based on the grey relation coefficient and the weighting coefficients of the indicators, the estimated levels of compliance with the requirements at the mine's production sites have been obtained by the Formula (4). As a result of the calculations, it has been determined that the best level of compliance with OSH requirements is noted at the sites of conveyor transport and assembling / disassembling operations (Table 6).

Table 5. Results of calculating weighting coefficients

Expert	Groups of requirements according to the ISO 4500:2018 standard groups of requirements						
	Organization's environment	Leadership	Planning	Ensuring	Functioning	Effectiveness	Improvement
No. 1	0.8	0.8	0.4	0.5	0.7	0.6	0.8
No. 2	0.7	0.9	0.4	0.6	0.6	0.5	0.7
No. 3	0.8	0.7	0.5	0.7	0.5	0.4	0.6
No. 4	0.5	0.6	0.6	0.6	0.6	0.6	0.5
No. 5	0.6	0.5	0.4	0.5	0.7	0.6	0.6
Average value of W	0.68	0.7	0.46	0.58	0.62	0.54	0.64

Table 6. Determination of a material level of non-compliance

Production site (unit)	Estimated level of compliance with the requirements at the mine's production sites	Percentage of estimated level of non-compliance with requirements, %	Rating of units for non-compliance with OSH requirements	Percentage of non-compliance with occupational safety requirements, %	Materiality of non-compliance with OSH requirements
Coal mining	1.15	11.8	4	37.6	Not material
Preparatory operations	0.96	9.8	3	25.8	Material
Mine transport	0.74	7.6	1	7.6	Material
Conveyor transport	2.26	23.3	7	100	Not material
Repair of mine workings	0.81	8.3	2	15.9	Material
Repair of face equipment	1.60	16.5	5	54.0	Not material
Assembling / disassembling operations	2.21	22.7	6	76.7	Not material
Total	9.73	100	–	–	–

$$R=E\cdot W=\begin{bmatrix}0.36&0.32&0.38&0.40&0.22&0.13&0.11\\0.14&0.32&0.24&0.20&0.32&0.24&0.14\\0.16&0.23&0.11&0.17&0.13&0.16&0.24\\0.25&0.40&0.30&0.49&0.77&0.87&0.69\\0.17&0.11&0.13&0.28&0.18&0.23&0.26\\0.40&0.49&0.57&0.18&0.32&0.30&0.40\\0.25&0.40&0.30&0.49&0.77&0.87&0.69\end{bmatrix}\cdot\begin{bmatrix}0.68\\0.70\\0.46\\0.58\\0.62\\0.54\\0.64\end{bmatrix}=\begin{bmatrix}1.15\\0.96\\0.74\\2.26\\0.81\\1.60\\2.21\end{bmatrix}.$$

Figure 2 shows the results of calculating the coefficient values for the level of non-compliance with OSH requirements in the coal mine units. The analysis of the above results (Table 6) and Figure 2 shows that significant non-compliance with OSH requirements at the sites of conveyor transport and assembling / disassembling operations is recorded at the level of 22-23%.

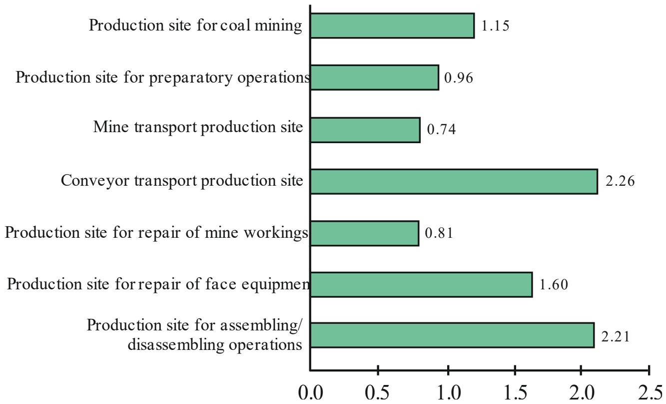

Figure 2. Results of calculating the coefficient values for the level of non-compliance with OSH requirements

In this case, a detailed analysis of the checklists received from these sites shows that most of the inconsistencies arise with compliance with the requirements of the ISO 45001:2018 standard sections, such as organization's environment, effectiveness and improvement (Fig. 3). At the same time, at the sites of conveyor transport and assembling / disassembling operations, non-compliance with the requirements from the section on ensuring is additionally added. This is primarily due to the complexity of production processes, the lack of monitoring of work performance and proper communication with employees to involve them in finding and implementing appropriate proposals for new or improving existing production technologies. Interestingly, the sections of the ISO 45001:2018 standard such as planning and analysis of the organization's environment are also characterized by a high percentage of non-compliance. This is due to the complexity of the mining-geological conditions, which cannot be fully taken into account during preliminary assessments based on known models. There is a need either to refine the models or to constantly monitor the situation, which will help to respond to possible changes in advance.

To improve the level of compliance with OSH requirements, it is recommended to develop maps and a program of measures to reduce occupational risks, taking into account non-compliance with OSH requirements [33], [34], with miners involved in the selection of precautionary measures. It is also necessary to organize safety awareness days to raise awareness of safety requirements and to form a safety leadership school with the involvement of experienced miners. Implement modern briefings using augmented reality technologies that will help to understand the development of possible emergencies and their consequences. In addition, it is desirable to create conditions for preventing hazards (motivational measures). The performed analysis to determine the coefficient of non-compliance with OSH requirements indicates that additional measures to improve compliance with OSH requirements are also needed at other studied production sites of the coal mine. In particular, this can include providing feedback from employees regarding safety objectives [35].

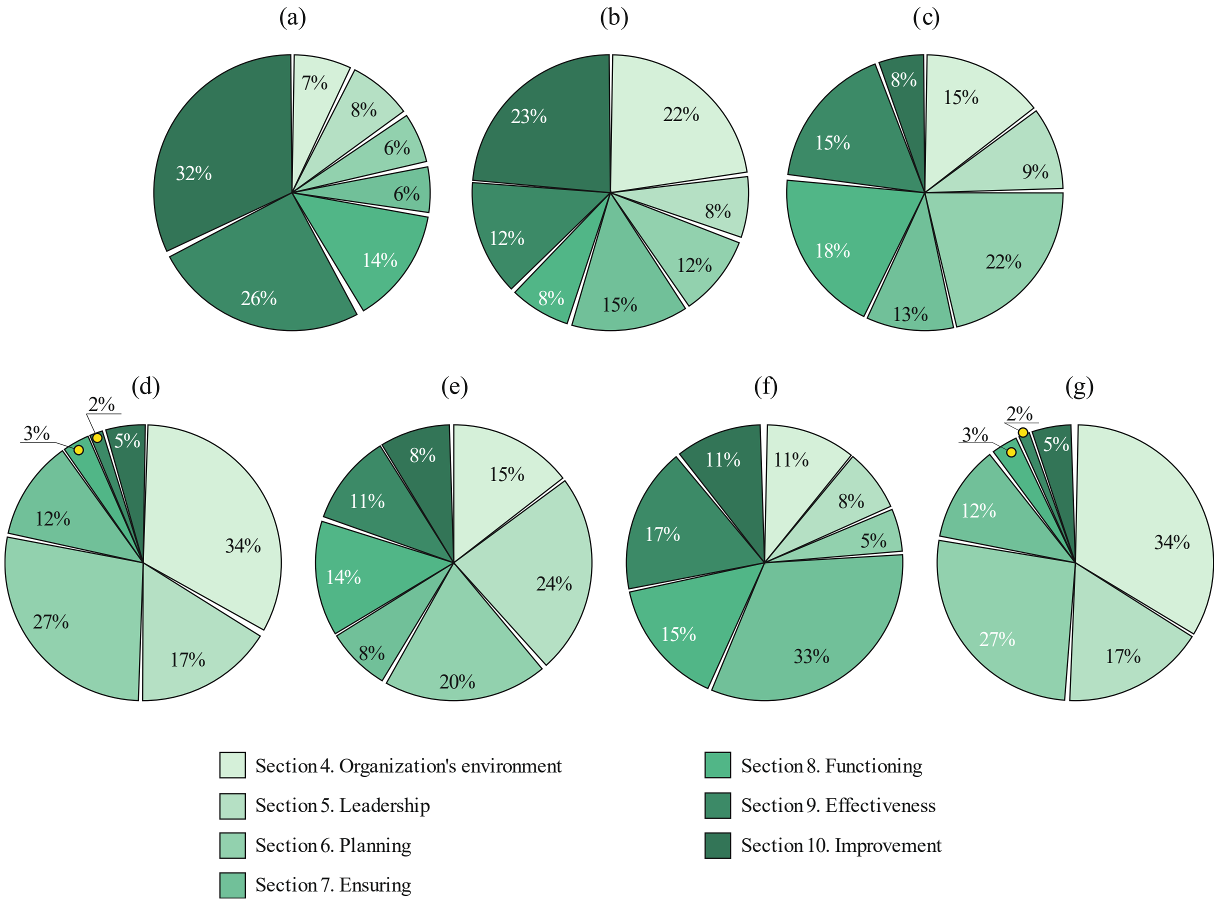

Figure 3. Distribution of the relative level of non-compliance with OSH requirements in accordance with the ISO 45001:2018 standard sections at the following sites: (a) coal mining; (b) preparatory operations; (c) mine transport; (d) conveyor transport; (e) repair of mine workings; (f) repair of face equipment; (g) assembling / disassembling operations

The presented results make it possible to identify the production sites of the mine where significant non-compliance with OSH requirements is recorded. This helps to determine the attitude of miners to fulfilling the OSH requirements based on the relationship between the coefficient of non-compliance with OSH requirements and the materiality criterion of non-compliance. Thus, in case of complete non-compliance with OSH requirements, which is in the range of 0-2%, it can be stated that an atmosphere of high awareness by employees has been created in the unit or site. If non-compliance with the requirements is within the range of 2 to 5%, this indicates an appropriate level of employee awareness of OSH requirements, while more than 5% indicates an inappropriate level of awareness that requires appropriate management.

This will allow for the implementation of actions to identify the causes and consequences of inconsistencies that affect the growth of occupational risks to an unacceptable level and will allow for an in-depth understanding of the causes of dangerous event occurrence and provide reasonable proposals for the application of precautionary and protective measures to eliminate the identified deficiencies. The reliability of the data obtained is ensured by the correct formulation of the problem and the use of the well-known Grey Relational Analysis method, which made it possible to rank the mining enterprise units according to the actual and target (reference) indicators of OSH requirements [36]. The advantages of the process proposed in this paper include the following: firstly, the coefficient of compliance with OSH requirements at the mine was estimated based on a comparison of compliance with the requirements at different production sites; secondly, an expert approach with data processing using the Grubbs' Test was used to calculate the weighting coefficients.

Similar results were obtained in [37]-[40], where grey analysis identified weaknesses in organizations' OSH management systems that led to an increase in employee injuries. The conclusion that can be drawn from these studies indicates the presence of a certain uncertainty in the assessment of occupational risks. This is due to uncertainty in determining the probability of a dangerous event occurrence and the severity of the consequences in the absence of a sufficient amount of statistical data. Especially when considering in detail the impact of various dangerous factors that occur periodically. Therefore, there is a need to search for alternative ways to calculate the level of risk with a certain degree of reliability. It is proposed to consider the coefficient of non-compliance with OSH requirements as a universal indicator for clarifying the probability of a dangerous event occurrence. This indicator can be determined by conducting observation, self-assessment, or audits. And the accumulation of data will help to identify relevant relationships with the level of injuries.

Further research in this area in the context of the relationship between dangerous factors and the level of occupational risks will be aimed at identifying the relationship between the materiality of non-compliance and the level of occupational risks. This will help to understand the degree of implementation of precautionary measures through employee compliance with the relevant requirements.

5. Conclusions

The nine-step process for determining the mining enterprise units with a significant level of non-compliance with OSH requirements of employees using the Grey Relational Analysis method has been developed, which allows, based on the relationship between the coefficient of compliance (non-compliance) with OSH requirements of employees and the materiality criterion of non-compliance with the requirements, to characterize the attitude of miners to OSH requirements.

A checklist for internal audit of units on compliance with OSH requirements of miners has been developed, which allows determining the coefficient of non-compliance with OSH requirements of miners in accordance with ISO 45001:2018 standard, as the ratio of positive and negative responses of auditors according to specified requirements.

Based on the results of calculating the numerical values of compliance with OSH requirements of miners, it has been determined that at the sites of conveyor transport and assembling / disassembling operations, the worst indicator of the coefficient of non-compliance of employees with the requirements is more than 20%, which shows a low level of their awareness of the need to comply with occupational safety requirements.

It is proposed to determine the materiality criterion of non-compliance with OSH requirements of employees as the difference between the reference and current level of compliance with OSH requirements of employees, which makes it possible to rank the mining enterprise units by the significant level of non-compliance with OSH requirements of employees.

Author contributions

Conceptualization: VT, SC; Data curation: DL; Formal analysis: OY; Funding acquisition: DL; Investigation: OY; Methodology: OD; Project administration: VT; Resources: DL; Software: OD; Supervision: DL; Validation: SC; Visualization: OD; Writing – original draft: OY; Writing – review & editing: SC. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Визначення підрозділів гірничого підприємства з суттєвим рівнем невиконання вимог безпеки праці на прикладі вугільної шахти

В. Цопа, О. Яворська, С. Чеберячко, О. Дерюгін, Д. Лантух

Мета. Розробка процесу визначення підрозділів гірничого підприємства з суттєвим рівнем невиконання вимог з безпеки праці та здоров'я працівників методом сірого реляційного аналізу.

Методика. Для визначення підрозділів гірничого підприємства з суттєвим рівнем невиконання вимог безпеки праці та здоров'я працівників застосовано метод сірого реляційного аналізу, який дозволяє провести ранжування підрозділів гірничого підприємства згідно фактичних і цільових (еталонних) показників.

Результати. Розроблено дев'яти кроковий процес визначення підрозділів гірничого підприємства з суттєвим рівнем невиконання вимог з безпеки праці та здоров'я працівників методом сірого реляційного аналізу. Запропоновано чеклист для внутрішнього аудиту підрозділів з питань виконання вимог з безпеки праці та здоров'я правників, який дозволяє визначити коефіцієнт невиконання вимог з безпеки праці та здоров'я правників у відповідності до стандарту ISO 45001:2018 як відношення позитивних і негативних відповідей аудиторів. Визначено, на основі результатів розрахунку числових значень виконання вимог з безпеки праці та здоров'я правників, що у дільницях конвеєрного транспорту та монтажно-демонтажних робіт найгірший показник коефіцієнту невиконання вимог, який складає більше 20%. Запропоновано визначати критерій суттєвості невиконання вимог з безпеки праці та здоров'я працівників як різницю між еталонним і поточним рівнем виконання вимог з безпеки праці та здоров'я працівників.

Наукова новизна полягає у встановленні взаємозв'язку між коефіцієнтом виконання (невиконання) вимог з безпеки праці та здоров'я працівників і критерієм суттєвості невиконання вимог, які характеризують ставлення правників до вимог з безпеки праці.

Практична значимість. Розроблено процес з визначення підрозділів гірничого підприємства з суттєвим невиконанням вимог з безпеки праці та здоров'я працівників, що дозволяє запровадити відповідні запобіжні й захисні заходи щодо зниження професійних ризиків.

Ключові слова: *підрозділ, гірниче підприємство, безпека праці, здоров'я працівників, вимоги до безпеки праці і здоров'я працівників*

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