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Investigating the role of human factors in the risk assessment of underground coal mines

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Abstract

Underground coal mines are always faced with their own specific uncertainties. These uncertainties lead to safety risks and ultimately result in chaos and safety disturbances. Human factors are among the uncertainties that play a vital role in various industries, including underground coal mining. For instance, they affect safety, production processes, machinery maintenance, and productivity. Risk management is one of the primary methods for improving safety in underground coal mines. Risk management is a process that helps identify, assess, and mitigate risks and uncertainties. Its main goal is to protect resources, enhance safety, and increase efficiency through informed decision-making. This article examines the role of human factors in risk assessment of coal mines; it first classifies human factors and then uses the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (Fuzzy-TOPSIS) method for pairwise comparison to evaluate the risks of underground coal mines. The TOPSIS method is a multi-criteria decision-making technique that operates based on the distance of options from the best and worst solutions. This method ranks the options based on specific criteria and assists in selecting the optimal option. The results of the study on human factors indicated that carelessness, negligence, and distraction had the greatest impact on the risk assessment of underground coal mines, with a similarity index of 0.6516, while the level of education had the least impact with a similarity index of 0.2871.

Keywords:
human factors; expert judgment; risk assessment; Fuzzy-TOPSIS; coal mines

1. Introduction

Human factor errors are prevalent across various sectors, significantly impacting safety and operational efficiency. Research indicates that the most common human errors stem from a lack of awareness and inadequate supervision. In occupational settings, human factors account for approximately 51.66% of work accidents, primarily due to insufficient worker awareness and adherence to safety protocols (**Yanti & Sugarindra, 2023**). In aviation maintenance, human errors are similarly critical, necessitating proactive interventions to identify and mitigate both active and latent human factors through systematic analysis. To address these issues, effective risk assessment and mitigation strategies are essential. These include enhancing supervision, improving standard operating procedures (SOPs), and fostering a culture of safety awareness among workers. Overall, a holistic strategy that combines awareness, training, and systematic evaluation is vital for reducing human errors and enhancing safety outcomes (**Bohrey & Chatpalliwar, 2024**) and (**Yanti & Sugarindra, 2023**).

Human factor risk assessments (HFRAs) play a crucial role in developing effective safety protocols in complex systems by systematically analyzing human interactions and potential errors (**Birch et al., 2023**). Conducting a human factor risk assessment in high-stakes industries requires a multifaceted approach that considers various elements influencing human behavior and performance. Key considerations include the identification of performance shaping factors (PSFs) and performance influencing factors (PIFs), which are critical for understanding how human interactions with technology and organizational structures can lead to errors and accidents (**Norazahar, 2020**). Overall, HFRAs contribute to a proactive safety culture by integrating human factors into safety management systems, thereby enhancing decision-making and risk-informed planning in socio-technical environments (**Paltrinieri, 2022**).

The human resource factor, as one of the organization's valuable assets that directly participate in producing goods and services, on the one hand, and as an intelligent agent and coordinator of other production factors, on the other hand, has a special place among other factors. Examining human factors aims to reduce human errors in a system and ultimately reduce casualties and injuries. On the other hand, work and people are two main and inseparable components of life, which will be most effective only if they are properly and correctly planned concerning each other.

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Determining the impact of human factors on mining risks includes the following steps:

- Identifying, classifying, and determining the most important human factors.
- Mine risks should be identified, and the most important of them should be determined and evaluated. In other words, the risk assessment method should be determined.
- Finally, the impact of human factors in the risk assessment of underground coal mines should be determined.

This research considers the three cases mentioned above and then presents some suggestions.

2. Human factors

2.1. Human factors concepts

Human factors or ergonomics is the fundamental and theoretical understanding of human behavior and performance to explain technical-social systems and apply them in designing technical-social systems in real contexts (**Paul et al., 2021**). Human factors engineering, or ergonomics, composed of two Greek words, "ergon" which means work and "nomos" which means laws (**Jafari Roodbandi et al., 2022**), is the science of adapting work to humans. In America, human factors engineering or human factors is synonymous with ergonomics. Ergonomics in Europe is rooted in work physiology, biomechanics, and workstation design. Despite the differences between human factors and ergonomics in terms of the knowledge type and design philosophy, these two approaches are nearing each other (**Read et al., 2022**), (**Symer et al., 2022**). So far, many terms have been used for ergonomics, including human factors, human factor engineering, human engineering, and engineering psychology (**Cameron et al., 2023**). Ergonomics or human engineering deals with the suitability of work and jobs with the human body, and while modifying and optimizing the work environment, jobs, and equipment and adapting the work environment to the limitations and capabilities of the worker's body, it prepares the conditions in a way to minimize stress and injury to the worker's body as a result of work or occupation (**Khattak et al., 2023**).

2.2. Human factor types

The classification of human factors depends on people's perspective types, which have evolved analyzed human factors in 12 chapters (including individual factors, physical factors, manual transportation of loads, collective trauma disorders, environmental factors, equipment design, work environment design, job factors, work schedules and fatigue and shift turnover, stress, team processes, behavior-based safety (**Attwood et al., 2004**). **Antonovsky et al. (2014)** conducted a study to identify common human factors cause breakdowns related to the maintenance of the oil industry; They found that the three most frequent human factors contributing to maintenance failures were found to be assumption (79% of cases), design and maintenance (71%), and communication (66%). Bochkovskyi and Sapozhnikova conducted a study in 2014 to develop strategies to minimize human factors in occupational health and safety. They found that the factors of professional training, development of quantitative and qualitative methods in occupational health and safety education system, creation of basic rules for teachers of occupational health and safety education system, and transfer of Ukraine's social insurance system to a risk-based concept are important factors to minimize the problem (**Bochkovskyi & Sapozhnikova, 2014**).

The SHELL model represents human error as a combination of hardware, software, live software (i.e. the human operator), and environmental conditions. This model divides human factors into four distinct levels, which encompass a total of 18 different components (**Patterson, 2009; Wiegmann & Shappell, 2000**). Wiegmann & Shappell. conducted a study in 2001 that categorized human errors into four categories: Organizational Influences, Unsafe Supervision, Preconditions of Unsafe Acts, and Unsafe Acts (**Wiegmann & Shappell, 2001**). **Mar et al. (2009)**, when researching the empathy methods and eliminating individual differences in social skills, referred to 10 items, including empathy skills, individual differences, age, and personality traits. Studying taste and work, **Peterson et al. (2009)** referred to individual enthusiasm, job satisfaction, general satisfaction, encouragement in the work environment, positive view in the organization, taste as a strong point of personality, and people's age. In positive psychology research, **Vazquez (2013)** discussed the principles that help promote mental health and more well-being in people's lives. Positive psychology explores the factors that enhance the quality of life and contribute to human happiness. This field encompasses topics such as personal growth and self-development, guiding individuals on their path to continuous improvement. Physical and mental health are also fundamental aspects of this science, emphasizing the value of both painful and beneficial experiences in shaping one's personality. Life values and positive emotions, such as joy and love, play a vital role in forming positive relationships. Self-awareness and purpose empower individuals to find meaning in their lives, while resilience enables them to overcome challenges. Additionally, self-confidence, creativity, and compassion act as personal strengths that enhance community and improve the quality of human relationships. Finally, achieving a balance between work and life is crucial for maintaining optimal well-being, and this comprehensive understanding contributes to defining a happy and meaningful life. **Dhillon (2014)** referred to the reasons affecting the occurrence of human errors in 11 parts, including performing activities too quickly, relying on luck and doing high-risk activities, and broken equipment. Bevilacqua et al. referred to the causes of human error in 14 cases, including forgetting a safe method or operation, wrong choice of raw material, not using personal protective equipment (PPE), and insufficient knowledge of regulations and procedures (**Bevilacqua & Ciarapica, 2018**). **Tong et al. (2019)** divided unsafe human behaviors into organizational and individual behaviors. In addition, they mentioned other factors, such as personal, organizational, and environmental factors, which are influential in the occurrence of unsafe behaviors. Personal behaviors include physiological and psychological factors.

Gorlenko and Murzin (2020) used parameters of working conditions, work experience in dangerous work conditions, age, and individuals' health status to determine the amount and complications of people's occupational risk in the work environment. Dhillon (1987) divided human error into six groups, including operating errors, assembly errors, design errors, inspection errors, and so on (**Dhillon, 1987**). **Margolis (2010)** examined human factors regarding age, experience, and occupational risks. Inexperience in the workforce may affect the severity of injuries in the mine. Training the workers is necessary to reduce risks among them. Investigating the geotechnical risks in underground coal mines, Shahriar and Bakhtawar (2009) pointed out risks such as collision, explosion, fall, sudden fall of stones, getting stuck between two objects, destruction, high temperature, electrocution, suffocation, and other risks (**Shahriar et al., 2009**). According to the cases mentioned above and the conducted research, human factors are divided into six groups, including individual factors (2 subgroups, 40 subdivisions), group factors (4 subgroups, 14 subdivisions), environmental factors (two subgroups, 39 subdivisions), organizational factors (3 subgroups, 16 subdivisions), regulatory factors (4 subdivisions), and national laws and regulations (4 subdivisions).

2.3. The pairwise comparison of human factors

A questionnaire was prepared to select the most important human factors, part of which is shown in **Table 1**. Regarding the number of experts, they need to be weighed. Therefore, the weighing of experts based on four parameters (including occupation, education, experience, and age) is shown in **Tables 2** and **3**.

The pairwise comparison questionnaire of human factors was completed by experienced experts and an example of it is shown in **Table 4.**

The pairwise comparison results of human factors have been calculated using MATLAB software (e.g. vector, and eigenvalue). **Tables 5**, **Figure 1** and **2** show an example of a paired comparison table, registered in MATLAB software, vector, eigenvalue, and standardized values of the HF matrix.

Table 1: Part of the human factors questionnaire

Human factors questionnaire										**Expert's No**								
Name and Surname:				**Date of Birth:**			**Education:**			**Work Experience:**			**Field of Study:**					
E-mail address:				**Place of activity:**			**Job:**			**Phone number:**			**Questionnaire completion date:**					
Dear expert: Please express your opinion about the importance of each of the following human factors																		
	1:9	**1:8**	**1:7**	**1:6**	**1:5**	**1:4**	**1:3**	**1:2**	**1:1**	**2:1**	**3:1**	**4:1**	**5:1**	**6:1**	**7:1**	**8:1**	**9:1**	
G1																		**I1**
O1																		**I1**
R1																		**I1**

Table 2: Calculating experts' weight

Scores given by expert					
Status	**Classification**	**Score**	**Status**	**Classification**	**Score**
Job	Managers and assistants	5	Education	PhD	5
	Superintendent and heads of mines	4		Bachelors and Masters	4
	Mining experts and officials	3		With a technical degree	3
	Workshop supervisor and foreman	2		Diploma	2
	Operator and worker	1		Below Diploma	1
Experience (year)	> 30	6	Age (year)	> 50	4
	20-30	5		40-50	3
	15-20	4		30-40	2
	10-15	3		< 30	1
	5-10	2			
	< 5	1			

Table 3: Experts' weights to calculate the importance of human factors and mining risks

Experts' weight for decision-making index						
Expert	**Job**	**Work experience**	**Education**	**Age**	**Total**	**weighing factor**
A_1	5	5	4	3	17	0.099
A_2	5	3	5	2	15	0.088
A_3	3	3	4	3	13	0.076
A_4	5	4	4	3	16	0.094
A_5	3	2	4	1	10	0.058
A_6	5	6	4	4	19	0.111
A_7	3	6	4	4	17	0.099
A_8	3	2	4	2	11	0.064
A_9	5	6	4	4	19	0.111
A_{10}	5	2	4	2	13	0.076
A_{11}	1	1	2	1	5	0.029
A_{12}	5	4	4	3	16	0.094
				Total	171	1000

The pairwise comparison results are given in the table below.

Eigenvector values of six human factors are as follows: individual factors (0.3460), group factors (0.1906), organizational factors (0.1235), regulatory factors (0.1972), environmental factors (0.0891), and country laws and regulations (0.0536). Therefore, individual factors were selected, as it has the highest value (e.g. 0.3460). Overall, 20 individual factors with higher values were selected and reported in **Table 6.**

2.4 The dangers of underground coal mines

In today's advanced world, where everyone relies on advanced, complex, and risky technology, there is always a fear that accidents and painful events caused by work lead to irreparable damage. Millions of work-related accidents occur in the world every year, some of which lead to death and others cause total or partial disability. Historically, the mine is one of the most dangerous workplaces in the world. Coal mines are more dangerous than metal mines, and it is obvious that underground coal mines are more dangerous than open-pit coal mines. To determine the impact of human factors on the risk of coal mines, one needs to identify the risks associated with these mines. These risks have been used as risk assessment criteria (**Wu et al., 2023**).

3. Identification and classification of hazards in underground coal mines

3.1. Background

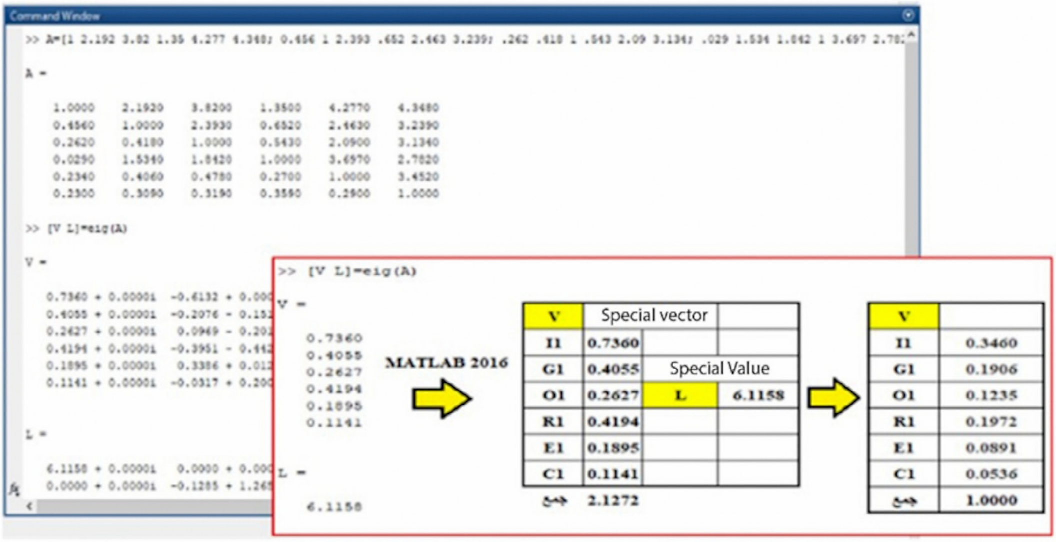
There are many studies on the identification and classification of risks in underground coal mines. Anvari (1995) described some mining accidents in American coal mines in 11 areas, including transportation, people's slippage or fall, and accidents caused by machinery (**Wu et al., 2023**). Behnoudi (2000) divided the harmful work environment factors into physical, chemical, biological, and ergonomic factors and determined their subcategories (**Bazaluk et al, 2023**). The **Geneva International Labour Office (2009)** referred to 14 health and safety risks for miners: mine explosions, mine fires, the fall of roofs and walls, and lung disease caused by dust inhalation in coal mines. **Siahuei et al. (2021)** aimed to evaluate and manage safety risks in underground mines. They found 45 risks, which they classified into 9 groups. Finally, they realized that airflow, the lack of proper scaling and post-blast scaling, and the absence of proper ventilation of dust are the main risks during underground mining. These risks are mostly related to blasting operations in the face and access tunnels. **Paithankar (2011)**

Table 4: Some results of the questionnaire on the importance of human factors

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	**After applying the expert weight**	
Group factors	3.000	2.000	4.000	2.000	2.000	0.111	2.000	1.000	5.000	3.000	0.167	0.500	2.192	Individual factors
Organizational factors	4	5	4.000	3.000	6.000	9.000	3.000	2.000	4.000	2.000	0.167	0.200	3.820	Individual factors
Regulatory factors	0.250	0.50	2.000	2.000	4.000	0.111	2.000	2.000	3.000	0.200	0.250	0.125	1.350	Individual factors

Table 5: The pairwise comparison of the human factor matrix (HF)

HF	**I1**	**G1**	**O1**	**R1**	**E1**	**C1**
I1	1.000	2.192	3.820	1.350	4.277	4.348
G1	0.456	1.000	2.393	0.652	2.463	3.239
O1	0.262	0.418	1.000	0.543	2.090	3.134
R1	0.029	1.534	1.842	1.000	3.697	2.782
E1	0.234	0.406	0.478	0.270	1.000	3.452
C1	0.230	0.309	0.319	0.359	0.290	1.000



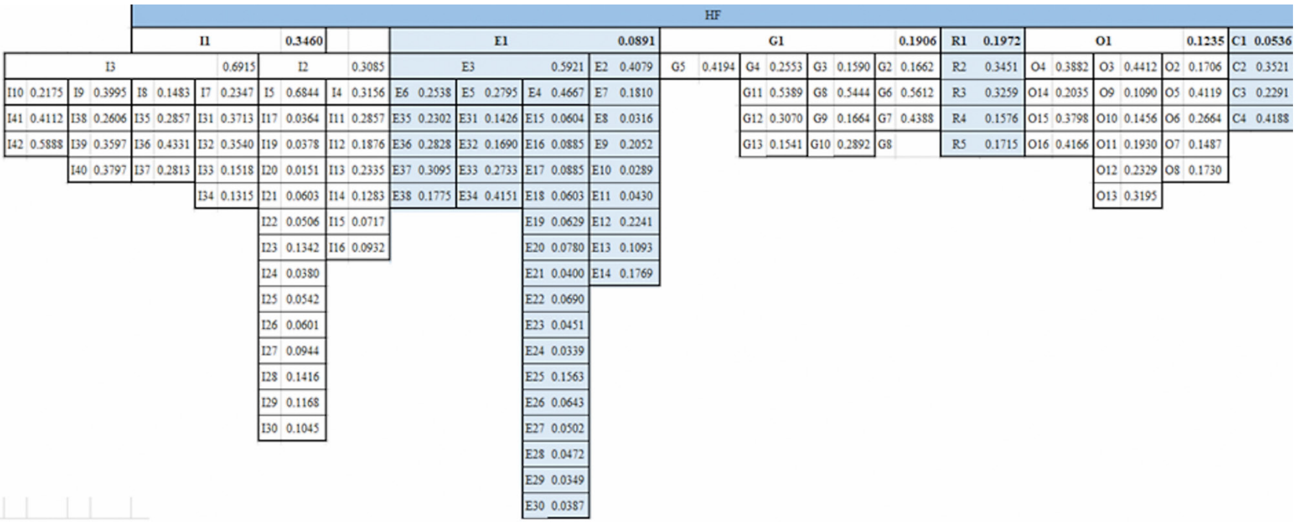
```
>> A=[1 2.192 3.82 1.35 4.277 4.348; 0.456 1 2.393 .652 2.463 3.239; .262 .418 1 .543 2.09 3.134; .029 1.534 1.842 1 3.697 2.78

A =

    1.0000    2.1920    3.8200    1.3500    4.2770    4.3480
    0.4560    1.0000    2.3930    0.6520    2.4630    3.2390
    0.2620    0.4180    1.0000    0.5430    2.0900    3.1340
    0.0290    1.5340    1.8420    1.0000    3.6970    2.7820
    0.2340    0.4060    0.4780    0.2700    1.0000    3.4520
    0.2300    0.3090    0.3190    0.3580    0.2900    1.0000

>> [V L]=eig(A)

V =

   0.7360 + 0.0000i  -0.6132 + 0.000
   0.4055 + 0.0000i  -0.2076 - 0.152
   0.2627 + 0.0000i   0.0949 - 0.202
   0.4194 + 0.0000i  -0.3951 - 0.442
   0.1895 + 0.0000i   0.3386 + 0.012
   0.1141 + 0.0000i  -0.0317 + 0.200


L =

   6.1158 + 0.0000i   0.0000 + 0.000
   0.0000 + 0.0000i  -0.1285 + 1.265
```

```
>> [V L]=eig(A)

V =

   0.7360
   0.4055
   0.2627
   0.4194
   0.1895
   0.1141


L =

   6.1158
```

V	Special vector	
I1	0.7360	
G1	0.4055	Special Value
O1	0.2627	L 6.1158
R1	0.4194	
E1	0.1895	
C1	0.1141	
جمع	2.1272	

V	
I1	0.3460
G1	0.1906
O1	0.1235
R1	0.1972
E1	0.0891
C1	0.0536
جمع	1.0000

Figure 2: The pairwise comparison result of human factors



HF																		
I1 0.3460						**E1 0.0891**				**G1 0.1906**				**R1 0.1972**	**O1 0.1235**			**C1 0.0536**
I3 0.6915				I2 0.3085		E3 0.5921			E2 0.4079	G5 0.4194	G4 0.2553	G3 0.1590	G2 0.1662	R2 0.3451	O4 0.3882	O3 0.4412	O2 0.1706	C2 0.3521
I10 0.2175	I9 0.3995	I8 0.1483	I7 0.2347	I5 0.6844	I4 0.3156	E6 0.2538	E5 0.2795	E4 0.4667	E7 0.1810		G11 0.5389	G8 0.5444	G6 0.5612	R3 0.3259	O14 0.2035	O9 0.1090	O5 0.4119	C3 0.2291
I41 0.4112	I38 0.2606	I35 0.2857	I31 0.3713	I17 0.0364	I11 0.2857	E35 0.2302	E31 0.1426	E15 0.0604	E8 0.0316		G12 0.3070	G9 0.1664	G7 0.4388	R4 0.1576	O15 0.3798	O10 0.1456	O6 0.2664	C4 0.4188
I42 0.5888	I39 0.3597	I36 0.4331	I32 0.3540	I19 0.0378	I12 0.1876	E36 0.2828	E32 0.1690	E16 0.0885	E9 0.2052		G13 0.1541	G10 0.2892	G8	R5 0.1715	O16 0.4166	O11 0.1930	O7 0.1487	
	I40 0.3797	I37 0.2813	I33 0.1518	I20 0.0151	I13 0.2335	E37 0.3095	E33 0.2733	E17 0.0885	E10 0.0289							O12 0.2329	O8 0.1730	
			I34 0.1315	I21 0.0603	I14 0.1283	E38 0.1775	E34 0.4151	E18 0.0603	E11 0.0430							O13 0.3195		
				I22 0.0506	I15 0.0717			E19 0.0629	E12 0.2241									
				I23 0.1342	I16 0.0932			E20 0.0780	E13 0.1093									
				I24 0.0380				E21 0.0400	E14 0.1769									
				I25 0.0542				E22 0.0690										
				I26 0.0601				E23 0.0451										
				I27 0.0944				E24 0.0339										
				I28 0.1416				E25 0.1563										
				I29 0.1168				E26 0.0643										
				I30 0.1045				E27 0.0502										
								E28 0.0472										
								E29 0.0349										
								E30 0.0387										

Figure 1: Registration in MATLAB software, vector, eigenvalue, and standardized values of HF matrix

Table 6: 20 individual factors with the highest scores

Human factors							
A_1	Intrinsic tendency for unsafe behavior	I_{11}	0.0278	A_{11}	Personal Protective Equipment (PPE) error	I_{33}	0.0246
A_2	Overconfidence	I_{12}	0.0183	A_{12}	Tool and equipment operation error	I_{34}	0.0213
A_3	Carelessness, negligence, and distraction	I_{13}	0.0227	A_{13}	Process flow error	I_{35}	0.0293
A_4	Height and weight	I_{23}	0.0283	A_{14}	Situational awareness error	I_{36}	0.0444
A_5	Level of training	I_{27}	0.0199	A_{15}	Risk assessment error	I_{37}	0.0288
A_6	Level of education	I_{28}	0.0299	A_{16}	Auditory error	I_{38}	0.0720
A_7	Level of competence	I_{29}	0.0247	A_{17}	Visual error	I_{39}	0.0994
A_8	Level of job knowledge	I_{30}	0.0221	A_{18}	Misjudgment	I_{40}	0.1049
A_9	Slip error	I_{31}	0.0603	A_{19}	Routine violations	I_{41}	0.0618
A_{10}	Technical errors	I_{32}	0.0575	A_{20}	Exceptional violations	I_{42}	0.0886

mentions a number of dangers of underground coal mines, including: roof collapse, falling walls, dumpers, explosives, electricity, air blasts/wind, fines or build-up of combustible particles, dusts that can affect health, and dusts that can effect operation and gas. These risks underscore the importance of comprehensive risk management strategies in coal mining operations. Effective hazard identification, regular training, and adherence to

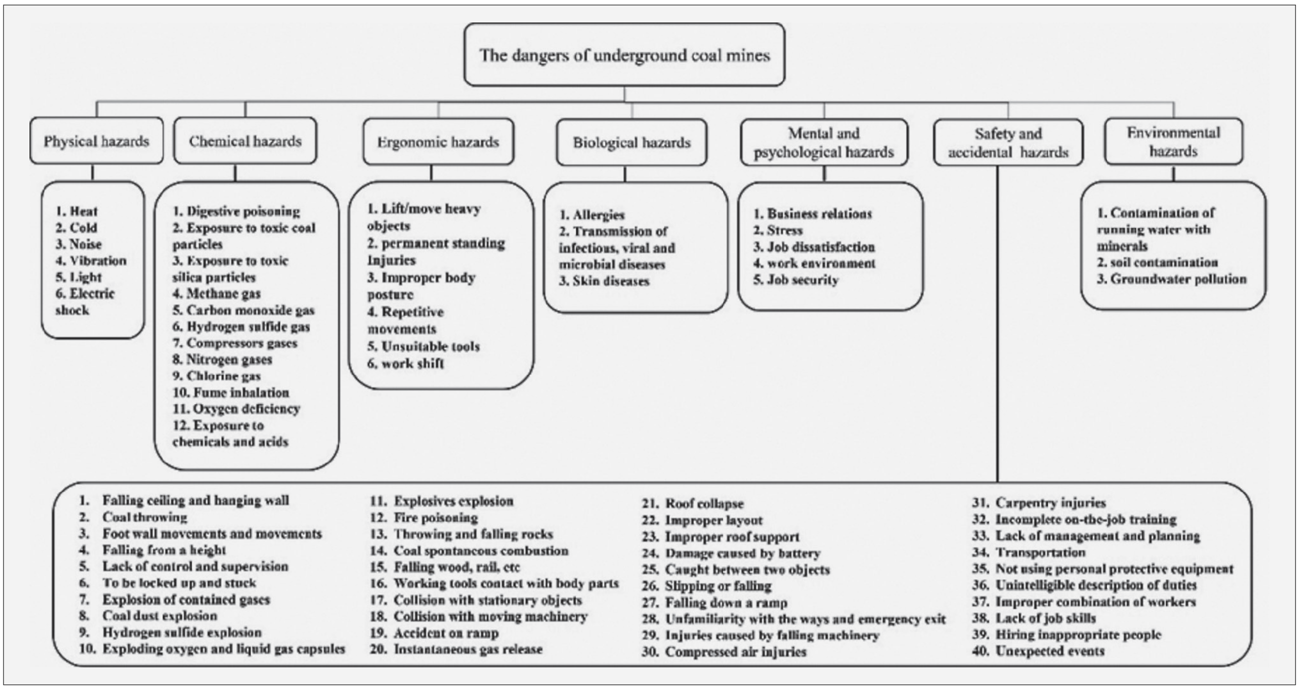


Figure 3: Classification of dangers in underground coal mines and subgroups of each category

Table 7: Part of the questionnaire on the impact of human factors on mining hazards

The questionnaire on the impact of human factors on mining hazards	**Expert number:**					
	The impact of human factors on mining hazards					
Hazards	**Very high**	**High**	**Moderate**	**Low**	**Very low**	**No hazard**
Heat (Hyperthermia, injuries caused by being burnt with hot objects and liquids, etc.)						
Cold (frostbite, etc.)						
Noise (caused by equipment and machinery and mining activities such as pickers, hammers, locomotives, etc.)						
Vibration caused by equipment and machinery and mining activities (including picker, hammer, locomotive, etc.)						
Lifting or moving heavy objects (wood, arches, rails, etc.)						
Injuries caused by long-standing						
Improper posture while working						
Repetitive movements						

Table 8: The weight of linguistic terms used to quantify experts' opinion

Fuzzy number	**The weight of linguistic terms**				
	Very low (VL)	**Low (L)**	**Moderate (M)**	**High (H)**	**Very high (VH)**
a1	0	0.1	0.3	0.6	0.8
a2	0	0.25	0.5	0.75	0.9
a3	0.1	0.25	0.5	0.75	1
a4	0.2	0.4	0.7	0.9	1

safety protocols are essential to minimize these dangers and protect the health and safety of workers in the mining industry.

According to the above studies and the study of risks and accidents in underground coal mines, especially the Shahrood Industrial and Mining Company and Eastern Alborz Coal Mines Company, as well as the risk assessment conducted in this field, the underground risks of coal mines are divided into 7 groups, as shown in **Figure 3**.

Table 9: Part of the questionnaire on the impact of human factors on mineral hazards in underground coal mines

Hazards	**Fuzzy number**	**Experts**											
		A_1	**A_2**	**A_3**	**A_4**	**A_5**	**A_6**	**A_7**	**A_8**	**A_9**	**A_{10}**	**A11**	**A12**
Heat (Hyperthermia, injuries caused by being burnt with hot objects and liquids, etc.)	A	VL	L	H	VL	L	H	VL	H	H	M	M	H
	a_1	0	0.1	0.6	0	0.1	0.6	0	0.6	0.6	0.3	0.3	0.6
	a_2	0	0.25	0.75	0	0.25	0.75	0	0.75	0.75	0.5	0.5	0.75
	a_3	0.1	0.25	0.75	0.1	0.25	0.75	0.1	0.75	0.75	0.5	0.5	0.75
	a_4	0.2	0.4	0.9	0.2	0.4	0.9	0.2	0.9	0.9	0.7	0.7	0.9
Cold (frostbite, etc.)	A	L	L	M	L	L	H	VL	L	M	L	VL	VL
	a_1	0.1	0.1	0.3	0.1	0.1	0.6	0	0.1	0.3	0.1	0	0
	a_2	0.25	0.25	0.5	0.25	0.25	0.75	0	0.25	0.5	0.25	0	0
	a_3	0.25	0.25	0.5	0.25	0.25	0.75	0.1	0.25	0.5	0.25	0.1	0.1
	a_4	0.4	0.4	0.7	0.4	0.4	0.9	0.2	0.4	0.7	0.4	0.2	0.2

Table 10: The results of 20 risks with the greatest impact on human factors

Hazard No.	**Hazards**	**FP**
H_1	Light (the lack of light in the tunnel, mining workshop, or intense light, e.g. during cutting and welding)	0.0240
H_2	Electricity and electrocution (injury, being burned, and damages resulting from it)	0.0266
H_3	Exposure to CH_4 gas in the mine	0.0460
H_4	Exposure to CO gas in the mine, produced by locomotive smoke, explosion, fire, etc.	0.0308
H_5	Improper posture while working	0.0268
H_6	Incompatibility of jobs with people's physical conditions	0.0203
H_7	Relations between workers and their colleagues and superiors and vice versa	0.0550
H_8	Stress (injuries caused by work stress such as workload, job responsibility, etc.)	0.0192
H_9	The lack of oxygen gas in mining works	0.0330
H_{10}	The lack of control and care of the department's responsible	0.0346
H_{11}	Coal gas explosion (methane gas, pit gas)	0.0678
H_{12}	Injuries caused by getting stuck between two hard objects such as a truck and wood, wagon, locomotive, arch, etc.)	0.0290
H_{13}	Collision with moving machinery (tunnel locomotive, wagon, tunnel loader, truck, etc.)	0.0324
H_{14}	Negligence in controlling, monitoring, and fixing the roof	0.0330
H_{15}	Fire (poisoning, being burned, and damages caused by it)	0.0236
H_{16}	The lack of management and planning	0.0709
H_{17}	Failure to use personal protective equipment	0.0620
H_{18}	Using an inappropriate combination of workers (in terms of experience and age)	0.0189
H_{19}	The lack of job skills	0.0228
H_{20}	Employing (physically) unsuitable people	0.0307

The questionnaire presented in **Table 7** identifies the impact of human factors on mining hazards. Since the questionnaire is fuzzy, **Table 8** was used to convert the weight of linguistic variables to quantitative values. This questionnaire was completed by 12 experts and part of its results are shown in **Table 9**. Regarding the number of experts, it was necessary to weigh them, so experts used **Table 2** to weigh them based on four parameters: occupation, education, experience, and age.

Regarding the fuzziness of the questionnaire, trapezoidal fuzzy numbers ~A = (a1, a2, a3, a4) are used (see **Table 20**). In addition, the fuzzy numbers were converted to definite numbers using the following relations.

$$X^* = \frac{1}{3}\frac{(a+a)^2 - aa - (a+a)^2 + aa}{(a+a-a-a)} \tag{1}$$

The resulting non-fuzzy numbers are in terms of possibility and need to be probabilistic. Therefore, the following relations were used:

$$\mathrm{CFP} = 0 \rightarrow \mathrm{FP} = 0, \mathrm{CFP} \neq 0 \rightarrow FP = \frac{1}{10^K} \tag{2}$$

$$K = [\frac{(1-CFP)}{CFP}]1/3 \times 2/301 \tag{3}$$

Where:

FP: The failure probability of any final event,

CFP: A possibility number resulting from the de-fuzzification step.

Table 10 shows the risk failure probability calculations and 20 selected hazards with higher failure probability.

4. The impact of human factors on risk assessment in underground coal mines using a similar to the ideal solution multi-criteria decision-making method (TOPSIS)

Risk refers to the dangers that a person is exposed to. It is derived from the Arabic word Riseq or the Greek word risicum (**Outreville, 1998**). The concept represents danger, uncertainty, and fear. Risk management is a functional process that involves recognizing sources of uncertainty, estimating the potential outcomes of risk/uncertain situations (risk analysis), and developing risk response strategies and anticipated outcomes (**Krause, 1999; Tamosaitiene et al., 2013**). On the one hand, risk management is a scientific approach, and on the other hand, it emphasizes the great problems and risks that individuals and companies are exposed to (**Kozarevic et al., 2014**). Risk assessment is an essential tool for the company's safety policy (**Marhavilas & Koulouriotis, 2008**). Quantitative and qualitative techniques can be used for risk assessment. Qualitative techniques such as checklists, risk assessment in the work environment, and failure mode and analysis are effective very simple, and scientific. Some quantitative evaluations are fault tree analysis and event tree analysis (**Ala & Tripathy, 2016**). Probability and loss parameters are needed to calculate risk (**Niczyporuk, 1996**).

The risk amount usually can be determined based on two parameters: probability and consequence. For more details on risk analysis, probability can be replaced by two parameters: probability and exposure. Exposure is the amount and time that personnel are exposed to hazards (**Ala & Tripathy, 2016**). The risk level is calculated according to **Equation 4** (**Niczyporuk, 1996**).

$$RL = P \times E \times C \tag{4}$$

Where RL is the risk level, P is the probability, E is exposure, and C is the consequence.

In two-dimensional and three-dimensional methods, the risk level is calculated by using two or three components. In addition, the level of two risks could be equal but their probability and severity could be unequal; in other words, the weight of risk components are not the same. On the other hand, it is not possible to use positive and negative components in risk, so, it is necessary to use multi-criteria risk assessment.

Multi-criteria decision-making is one of the most widely used optimization problems, in which decisions are made based on several criteria. In general, multi-criteria optimization problems are divided into two categories: multi-objective decision-making and multi-criteria decision-making. Various multi-criteria decision-making (MCDM) techniques are used as the main ranking tool in complex and multi-dimensional problems. In such problems, the decision-maker usually ranks the available options or chooses an option out of different options based on the criteria importance. Methods such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytical Hierarchy Process (AHP), Taxonomy Analysis Method, and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS), Fuzzy Analytical Hierarchy Pro-

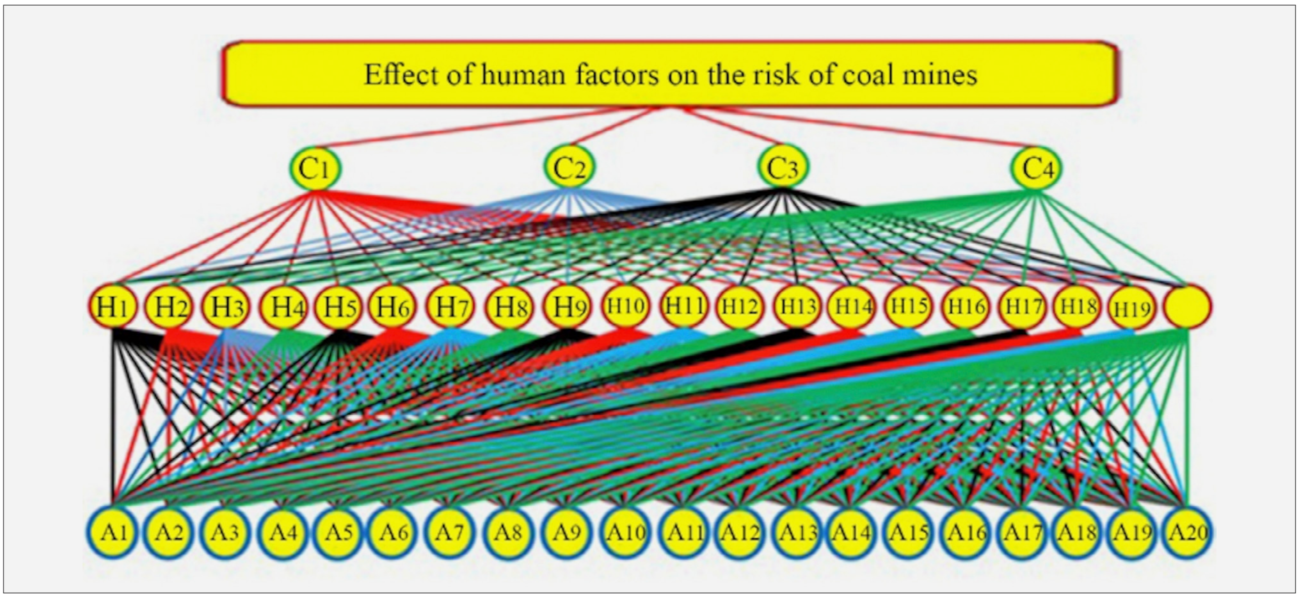


Figure 4: The effect of human factors on risk assessment in underground coal mines

cess (FAHP), and Fuzzy Delphi Analytical Hierarchy Process (FDAHP) are the most effective multi-criteria decision-making techniques. This article uses the similarity to the ideal solution (TOPSIS), which has a strong mathematical foundation, to assess the risks (**Pouresmaieli et al., 2011**).

4.1. Determining indicators, criteria and options

This evaluation uses four decision-making indicators: the occurrence probability, effect level, estimation uncertainty, and organization's ability to react to risk. Twenty hazards were used as decision-making criteria and 20 human factors were used as risk assessment options. **Figure 4** shows the influence of human factors on the risk assessment in underground coal mines.

Regarding the results obtained from the second and third parts of the article, the value of criteria in **Table 11**, measures (risks) in **Table 10**, and risk assessment options (human factors) in **Table 6** are presented.

The criteria for risk assessment include the organization's ability to respond to risks, estimated uncertainty, level of impact, and the occurrence probability, each formulated with specific logic. The ability to respond to risks refers to identifying the organization's internal capacities for managing and controlling risks. Estimated uncertainty addresses the accuracy and reliability of predictions, helping to reduce errors. The level of impact indicates how a specific risk affects the organization's objectives and processes, while likelihood of occurrence assesses the probability of a particular risk event. The combination of these four criteria helps organizations gain a comprehensive understanding of their risk situation and make better decisions in risk management.

Table 11: Risk assessment indicators

Decision-making criteria	
C_1	The occurrence probability
C_2	Impact level
C_3	Estimation uncertainty
C_4	Organization's ability to respond to risks

4.2. Determining the weight of indicators

A questionnaire was prepared and given to 12 experts to compare indicators in a pairwise manner.

The experts gave the weights according to **Table 2**. The result of pairwise comparison is shown in **Table 12**.

Table 12: The pairwise comparison matrix of criteria

HF	**C_1**	**C_2**	**C_3**	**C_4**
C_1	1.000	4.044	5.678	2.878
C_2	0.247	1.000	5.310	4.559
C_3	0.176	0.188	1.000	0.542
C_4	0.347	0.219	1.845	1.000

The entropy method was used for pairwise comparison of the HF matrix. Shannon's entropy method can be used to determine the criteria weights. This method was first presented in 1974 by Shannon and Weaver. Entropy expresses the uncertainty amount in a continuous probability distribution. The main idea behind this method is that the greater the dispersion of criterion value, the more important entropy is, and as a weighing method, it is calculated based on the dispersion in the values of a criterion. Entropy in information theory is a measure of uncertainty expressed by the probability distribution function Pi. Shannon measured this uncertainty (Ei) by using **Equation 5** (**Ataei, 2010**). An example of this method's matrix is shown in **Table 13**.

Table 13: Decision-making matrix

	C_1	**…**	**C_n**
A_1	a_{11}		a_{1n}
…	…	…	…
A_m	a_{m1}		a_{mn}

$$\mathrm{Ei} = \mathrm{S(P1, P2, \ldots, Pn)} = -\mathrm{K}\sum\nolimits_{i=0}^{n}[p_i \times In\ P_i] \qquad (5)$$

Where K is a constant value that causes E_i (entropy) to be placed between 0-1. The value of K is given by **Equation 6**:

$$K = \frac{1}{\ln m} \qquad (6)$$

P_{ij} (i.e. the distribution function of criterion *ij*) can be calculated using **Equation 7**:

$$P_{ij} = \frac{a\ ij}{\sum\nolimits_{i=1}^{m} a\ ij}; \forall_{ij} \qquad (7)$$

Where:

m is the number of considered options, a_{ij} is the score of criterion *i* for option *j*. Then, the entropy of criterion j (*Ej*) is given by **Equation 8**:

$$E_j = -k\sum\nolimits_{i=1}^{n}[p_i \times In\ Pij]; \forall_{ij} \qquad (8)$$

Uncertainty or the degree of deviation (*dj*) from the obtained information for criterion *j* expresses how much useful information is provided by decision-makers for making decisions. The value of *dj* is obtained from **Equation 9**:

$$d_i = 1 - E_j; \forall_j \qquad (9)$$

Then, the weight value of criterion W_j is determined using **Equation 10**:

$$W_j = \frac{dj}{\sum\nolimits_{i=1}^{n} dj}; \forall_j \qquad (10)$$

The distribution function of criteria is calculated using **Equation 9** and the corresponding results are shown in **Table 14**.

Table 14: The distribution function of criteria ij (P_{ij})

P_{ij}	**C_1**	**C_2**	**C_3**	**C_4**
C_1	0.565	0.742	0.410	0.321
C_2	0.140	0.183	0.384	0.508
C_3	0.099	0.034	0.072	0.060
C_4	0.196	0.040	0.133	0.111

The entropy level, uncertainty, and weight of criteria are calculated using **Equations 10**, **11**, and **12**, in order, and their results are shown in **Table 15**.

Table 15: The entropy matrix, uncertainty, and the criteria weight

	C_1	**C_2**	**C_3**	**C_4**
E_j	0.82687	0.56108	0.859538	0.80983
d_j	0.17313	0.43892	0.140462	0.19017
W_j	0.18365	0.465599	0.149	0.20173

The pairwise comparison results of the criteria are described in **Table 16.**

Table 16: The results of the indicator's weight

The organization's ability to respond to risk	**The uncertainty of estimation**	**The impact level**	**The occurrence probability**
0.20173	0.149	0.465599	0.18365

4.3. Determining the Criteria's weight

In this section, hazards are compared according to each of the decision-making criteria, and the results are reported in the matrices related to those decision-making criteria. The questionnaire was prepared and completed by six experts. Weighing was performed based on **Table 7**. **Table 17** presents part of the pairwise comparison results of risks concerning the C1 evaluation criterion.

The entropy method was used to calculate the risk's weights. The values of Pij, Ej, dj, and Wj for decision criteria C2, C3, and C4 were calculated using **Equations 9**, **10**, **11**, and **12**. The obtained results are shown in **Table 18**.

4.4. Determining the weight of solutions

A pairwise comparison on the importance of 20 human factors (solutions) was done considering each of the 20 risks. The entropy method was used to calculate the solutions' weights. In addition, the values of P_{ij}, E_j, d_j, and W_j were calculated using **Equations 7**, **8**, **9**, and **10**, respectively.

Pairwise comparison questionnaires of human factors were prepared and completed by 6 experts. The experts weighed them based on **Table 2.** A part of the pairwise comparison result of 20 human factors, according to the risk H1, is given in **Table 19**.

The values E_i, P_{ij}, D_i, and W_i of human factors (solutions) about each hazard (measure) were calculated using **Equations 9**, **10**, **11**, and **12**, in order, and the results are shown in **Table 20.**

5. The impact of human factors in the risk assessment of underground coal mines using the multi-criteria decision-making method (TOPSIS)

5.1. Determining the risk assessment indicators of underground coal mines

According to the weights given to the criteria, it is necessary to determine the signs of criteria in the TOP-

Table 17: Part of the pairwise comparison results' matrix on the importance of risks based on the C_1 criterion

C_1	**H_1**	**H_2**	**H_3**	**H_4**	**H_5**	**H_6**	**H_7**	**H_8**	**H_9**	**H_{10}**	**H_{11}**	**H_{12}**	**H_{13}**	**H_{14}**	**H_{15}**	**H_{16}**	**H_{17}**	**H_{18}**	**H_{19}**	**H_{20}**
H_1	1	1.68	1.45	0.96	2.16	2.49	2.09	2.16	1.45	1.92	1.21	1.32	1.32	1.37	1.58	1.79	2.08	2.66	2.2	2.82
H_2	0.6	1	2.8	0.85	1.45	1.89	1.08	1.46	0.56	0.99	0.2	0.75	0.91	0.6	0.96	1.04	0.81	1.13	1.46	1.46

Table 18: The results of comparing the importance of risks relative to each other according to the decision-making criteria

	C_1	**C_2**	**C_3**	**C_4**		**C_1**	**C_2**	**C_3**	**C_4**
H_1	0.0122	0.0309	0.0494	0.0370	H11	0.0449	0.0462	0.0320	0.0318
H_2	0.0543	0.0425	0.0348	0.0466	H12	0.0295	0.0678	0.0576	0.0588
H_3	0.4391	0.0847	0.0408	0.1153	H13	0.0257	0.0687	0.0716	0.0675
H_4	0.0337	0.0747	0.0600	0.0724	H14	0.0361	0.0623	0.0697	0.0620
H_5	0.0286	0.0241	0.0252	0.0241	H15	0.0283	0.0120	0.0804	0.0969
H_6	0.0179	0.0253	0.0231	0.0265	H16	0.0364	0.0645	0.0619	0.0560
H_7	0.0361	0.0377	0.0532	0.0392	H17	0.0391	0.0574	0.0207	0.0363
H_8	0.0410	0.0850	0.0549	0.0744	H18	0.0211	0.0250	0.0204	0.0169
H_9	0.0221	0.0517	0.1172	0.0744	H19	0.0238	0.0295	0.0505	0.0318
H_{10}	0.0249	0.0392	0.0547	0.0476	H20	0.0162	0.0193	0.0217	0.0187

Table 19: A part of the importance matrix for each human factor concerning hazard H1

H1	A1	A2
A1	1	0.283
A2	3.538	1
A3	3.538	3.384
A4	3.807	3.731
A5	3.807	3.731
A6	3.807	3.731
A7	3.807	3.731
A8	3.641	3.628
A9	3.558	3.628
A10	0.248	0.282
A11	2.484	2.506
A12	0.212	0.246
A13	3.294	3.384
A14	3.294	3.384
A15	3.641	3.243
A16	3.641	3.731
A17	3.641	3.731
A18	3.237	3.224
A19	3.641	3.731
A20	3.641	3.731

Table 20: A part of the pairwise comparison matrix of human factors (solutions) considering the mining hazards (measures)

	A1	A2
H1	0.1185	0.0767
H2	0.0789	0.1090
H3	0.0467	0.0784
H4	0.0119	0.0726
H5	0.0281	0.0706
H6	0.0883	0.1042
H7	0.0668	0.0578
H8	0.0217	0.0730
H9	0.1196	0.0899
H10	0.0919	0.0914
H11	0.0239	0.1075
H12	0.1068	0.0971
H13	0.0529	0.0786
H14	0.1114	0.0933
H15	0.0868	0.1121
H16	0.0882	0.0914
H17	0.1177	0.0567
H18	0.0326	0.0454
H19	0.0129	0.0752
H20	0.0822	0.0853

SIS multi-criteria decision risk assessment. In this method, the negative or positive sign and the criteria's weights are explained in **Table 21.**

5.2. *Determining the values of criteria in risk assessment by TOPSIS method*

Table 22 shows part of the results of the criteria's weight for each criterion.

Table 21: The signs of risk assessment criteria

Index	C1	C2	C3	C4
Sign	+	+	-	-
Weight	0.1837	0.4656	0.1490	0.2017

Table 22: A part of the weight results' hazards for each criterion

	C1	C2	C3	C4
H1	0.0194	0.0309	0.0494	0.0370
H2	0.0863	0.0425	0.0348	0.0466
H3	0.0907	0.0847	0.0408	0.1153
H4	0.0535	0.0747	0.0600	0.0724

In the method of similarity to the ideal solution, **Equation 11** is used to standardize matrix $C = (x_{ij})_{m\times n}$ for positive and negative criteria (**Ala and Tripathy, 2016**).

$$X = \begin{cases} \dfrac{\text{bmn} - \text{bn min}}{\text{bn max max} - bn\ min}, \Big| \textit{Positive criterion} \\ \dfrac{bn \max\max - bmn}{bn \max\max - bn\ min}, \Big| \textit{Negative criterion} \end{cases} \tag{11}$$

The results of the standardized criteria matrix are shown in **Table 23.**

The weighed Stoddard matrix of the criteria was calculated, i.e. $Y = (y_{ij})_{m\times n}$.

$$\text{yij} = \text{wj xij } (\text{i} = 1, 2, \ldots, \text{m}; \text{j} = 1, 2, \ldots, \text{n}) \tag{12}$$

The standardized weighed matrix is shown in **Table 24.**

In the next step, the ideal and anti-ideal solutions are shown by (R+) and (R-), and their values are obtained from **Equation 15** (**Ala and Tripathy, 2016**).

$$R^{+} = \left\{ \underset{i}{\max}(r'_{ij}) \middle| i \in (1, m); j \in (1, n) \right\} \tag{13}$$

Table 23: The standardized matrix of criteria (C)

	C1	C2	C3	C4		C1	C2	C3	C4
H1	0.0000	0.1150	0.7004	0.7957	H11	0.7307	0.2666	0.8802	0.8486
H2	0.9383	0.2299	0.8512	0.6982	H12	0.3857	0.4807	0.6157	0.5742
H3	1.0000	0.6482	0.7893	0.0000	H13	0.3015	0.4896	0.4711	0.4858
H4	0.4783	0.5491	0.5909	0.4360	H14	0.5330	0.4262	0.4907	0.5417
H5	0.3661	0.0476	0.9504	0.9268	H15	0.3576	1.0000	0.3802	0.1870
H6	0.1262	0.0595	0.9721	0.9024	H16	0.5400	0.4480	0.5713	0.6026
H7	0.5330	0.1824	0.6612	0.7734	H17	0.6003	0.3776	0.9969	0.8028
H8	0.6438	0.0912	0.6436	0.7622	H18	0.1978	0.0565	1.0000	1.0000
H9	0.2202	0.3211	0.0000	0.4157	H19	0.2581	0.1011	0.6890	0.8486
H10	0.2819	0.1972	0.6457	0.6880	H20	0.0884	0.0000	0.9866	0.9817

Table 24: The standardized weighed matrix of criteria (Y_{ij})

	C1	C2	C3	C4		C1	C2	C3	C4
H1	0	0.05353	0.10436	0.16052	H11	0.1342	0.12413	0.13114	0.17118
H2	0.17232	0.10706	0.12683	0.14084	H12	0.07083	0.2238	0.09174	0.11583
H3	0.18365	0.30179	0.1176	0	H13	0.05538	0.22795	0.07019	0.09799
H4	0.08783	0.25564	0.08805	0.08795	H14	0.09788	0.19842	0.07311	0.10927
H5	0.06723	0.02215	0.14161	0.18697	H15	0.06568	0.4656	0.05664	0.03772
H6	0.02318	0.02769	0.14484	0.18205	H16	0.09917	0.20857	0.08512	0.12157
H7	0.09788	0.08491	0.09851	0.15601	H17	0.11024	0.17581	0.14854	0.16196
H8	0.11823	0.04245	0.0959	0.15376	H18	0.03632	0.0263	0.149	0.20173
H9	0.04044	0.14951	0	0.08385	H19	0.04739	0.04707	0.10267	0.17118
H10	0.05177	0.09183	0.0962	0.13879	H20	0.01623	0	0.147	0.19804

$$R^- = \left\{ \min_{i}(r'_{ij}) \middle| i \in (1,m); j \in (1,n) \right\} \qquad (14)$$

Therefore, the best and worst criteria are calculated and shown in **Table 25.**

Table 25: Ideal (R+) and anti-ideal (R-) solutions

R+	0.1837	0.4656	0.1490	0
R-	0	0	0	0.20173

The distance from ideal and anti-ideal solutions for each criterion is calculated using **Equations 15** and **16**, respectively (**Ala and Tripathy, 2016**).

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \varepsilon j (r'ij - r^+ j)^2} \qquad (15)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \varepsilon j (r'ij - r^- j)^2} \qquad (16)$$

In the final stage, **Equation 17** is used to calculate the similarity (C_i) (**Ala and Tripathy, 2016**).

$$c_i = \frac{d^- i}{d^+ + d^-}, i\epsilon(1,\mathrm{m}) \qquad (17)$$

Where: In this context, index j represents the criterion, and index i represents the option being considered.

d_i^+ is the distance of each option from the ideal limit, d_i^- is the distance of each option from the anti-ideal limit.

The values of d+, d-, and C_i are shown in **Table 26.**

The values of hazards are shown in **Table 27**, which are calculated based on the similarity index.

5.3. Determining the similarity criteria of human factors (solutions)

In this section, we determine the sign and weight of the criteria shown in **Table 28**.

The matrix of pairwise comparison results is calculated for each criterion. In the method of similarity to the ideal solution, **Equation 13** is used to standardize the matrix C = $(x_{ij})_{m\times n}$ for positive and negative criteria, and some of the results are shown in **Table 29**.

Equation 14 was used to determine the weighed standardized matrix of criteria (Y= $(y_{ij})_{m\times n}$). A part of the weighed standardized matrix is shown in **Table 30**.

In the next step, the value of ideal (R+) and anti-ideal (R-) solutions were calculated using **Equations 15** and **16**, respectively, and the results are shown in **Table 31.**

The hazard of distance from ideal and anti-ideal solutions was calculated using **Equations 14** and **15**, respectively. In the final step, **Equation 18** was used to calcu-

Table 26: The values of d^+, d^- and C_i

	d^+	d^-	C_i		d^+	d^-	Ci
H1	0.4809	0.1243	0.2054	**H11**	0.3856	0.2270	0.3706
H2	0.3860	0.2469	0.3901	**H12**	0.2965	0.2663	0.4731
H3	0.1668	0.4235	0.7174	**H13**	0.2979	0.2659	0.4716
H4	0.2544	0.3062	0.5462	**H14**	0.3106	0.2507	0.4467
H5	0.4952	0.1590	0.2430	**H15**	0.1545	0.5012	0.7643
H6	0.5007	0.1506	0.2312	**H16**	0.3034	0.2588	0.4604
H7	0.4233	0.1691	0.2854	**H17**	0.3400	0.2583	0.4317
H8	0.4580	0.1651	0.2650	**H18**	0.5054	0.1556	0.2354
H9	0.3869	0.1946	0.3347	**H19**	0.4746	0.1262	0.2101
H10	0.4233	0.1560	0.2693	**H20**	0.5330	0.1479	0.2173

Table 27: The hazard values based on the similarity index

Hazards		C_i
Fire (poisoning, being burned, and damages caused by it)	H15	0.7643
Exposure to CH4 gas in the mine	H3	0.7174
Exposure to CO gas in the mine, produced by locomotive smoke, explosion, fire, etc.	H4	0.5462
Being trapped between two stiff objects (locomotive, wagon, wood, truck, etc.)	H12	0.4731
Collision with moving machinery (tunnel locomotive, wagon, tunnel loader, truck, etc.)	H13	0.4716
The lack of management and planning	H16	0.4604
Negligence in controlling, monitoring, and fixing the roof	H14	0.4467
Failure to use personal protective equipment	H17	0.4317
Electricity and electrocution (injury, being burned, and damages resulting from it)	H2	0.3901
Coal gas explosion (methane gas, pit gas)	H11	0.3706
The lack of oxygen gas in mining works	H9	0.3347
Relations between workers and their colleagues and superiors and vice versa	H7	0.2854
Improper posture while working	H5	0.2430
Incompatibility of jobs with people's physical conditions	H6	0.2312
The lack of control and care of the department's responsible	H10	0.2693
Stress	H8	0.2650
Using an inappropriate combination of workers (in terms of experience and age)	H18	0.2354
Employing (physically) unsuitable people	H20	0.2173
The lack of job skills	H19	0.2101
Light	H1	0.2054

Table 28: The signs of risk assessment criteria

Hazard	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20
Sign	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+
Hazard weight	0.2054	0.3901	0.7174	0.5462	0.2430	0.2312	0.2854	0.2650	0.3347	0.2693	0.3706	0.4731	0.4716	0.4670	0.7643	0.4604	0.4317	0.2354	0.2101	0.2173

Table 29: A part of the standardized matrix of criteria (C)

C	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**	**H10**	**H11**	**H12**	**H13**	**H14**	**H15**	**H16**	**H17**	**H18**	**H19**	**H20**
A1	1.0000	0.7083	0.4235	0.0234	0.1640	0.6411	0.6965	0.1025	1.0000	0.0000	0.1185	1.0000	0.4921	1.0000	0.3946	0.3078	0.0000	0.2262	0.0000	0.6879
A2	0.6304	1.0000	0.7626	0.5141	0.6547	0.7766	0.7406	0.6559	0.7273	0.0061	0.9875	0.8983	0.8629	0.8206	0.5204	0.2800	0.5854	0.3907	0.5911	0.7182

Table 30: A part of the standardized weighed matrix of criteria

Y_{ij}	H_1	H2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}	H_{12}	H_{13}	H_{14}	H_{15}	H_{16}	H_{17}	H_{18}	H_{19}	H_{20}
A_1	0.2054	0.2763	0.3038	0.0128	0.0398	0.1482	0.1988	0.0272	0.3347	0.0000	0.0439	0.4731	0.2321	0.4670	0.3016	0.1417	0.0000	0.0533	0.0000	0.1495
A_2	0.1295	0.3901	0.5471	0.2808	0.1591	0.1796	0.2114	0.1738	0.2434	0.0016	0.3660	0.4250	0.4070	0.3832	0.3977	0.1289	0.2527	0.0920	0.1242	0.1561

Table 31: Ideal (R+) and anti-ideal (R-) solutions

	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}	H_{12}	H_{13}	H_{14}	H_{15}	H_{16}	H_{17}	H_{18}	H_{19}	H_{20}
R+	0.2054	0.3901	0.7174	0.5462	0.2430	0.2312	0.0000	0.2650	0.3347	0.2693	0.3706	0.4731	0.4716	0.4670	0.7643	0.4604	0.4317	0.2354	0.2101	0.2173
R-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2854	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 32: The values of d^+, d^- and C_i

	d^+	d^-	C_i		d^+	d^-	C_i
A1	1.1972	0.9944	0.4537	A11	0.7911	1.4544	0.6477
A2	0.7546	1.2702	0.6273	A12	1.1634	0.7963	0.4063
A3	0.7356	1.3755	0.6516	A13	1.0475	0.8858	0.4582
A4	1.6736	0.6943	0.2932	A14	0.9505	0.9850	0.5089
A5	1.0983	0.8537	0.4373	A15	0.9408	0.9860	0.5117
A6	1.6044	0.6462	0.2871	A16	1.4057	0.6856	0.3278
A7	1.4482	0.5939	0.2908	A17	1.3327	0.6800	0.3378
A8	1.1615	0.8599	0.4254	A18	1.1805	0.7674	0.3940
A9	1.2889	0.8049	0.3844	A19	1.3814	0.6571	0.3224
A10	1.3381	0.7976	0.3735	A20	1.4640	0.6528	0.3084

Table 33: The division of solutions based on the similarity index (C_i)

Human Factors		**C***	**Human Factors**		**C***
Carelessness, negligence, and distraction	A_3	0.6516	Wrong judgment	A18	0.3940
Failure to use personal protective equipment	A_{11}	0.6477	Inadvertent error	A9	0.3844
Overconfidence	A_2	0.6273	Technical errors	A10	0.3735
Risk assessment error	A_{15}	0.5117	Visual error	A17	0.3378
Status detection error	A_{14}	0.5089	Hearing error	A16	0.3278
Workflow error	A_{13}	0.4582	Routine violations	A19	0.3224
A person's internal tendency to perform unsafe behaviors	A_1	0.4537	Exceptional violations	A20	0.3084
Training amount	A_5	0.4373	Height and weight	A4	0.2932
The amount of work information	A_8	0.4254	Competency	A7	0.2908
The error of working with tools and equipment	A_{12}	0.4063	Education level	A6	0.2871

late the similarity index (*Ci*). The values of d+, d-, and *Ci* are shown in **Table 32**. The solutions are divided and shown in **Table 33** based on the values of C_i.

6. Conclusions

According to the similarity index, the human factors carelessness, negligence, and distraction with a value of 0.6516 had the highest value, and education with a value of 0.2871 had the lowest impact value among the hazards of underground coal mines. The human factors that have the most significant impact on hazards in coal mines include carelessness, negligence, distraction, the failure to use personal protective equipment, and overconfidence. Conversely, the factors that have the least impact on the risks associated with underground coal mining are the level of education, competence, height, and weight.

To enhance safety and efficiency in the workplace, several suggestions can be implemented. First, it is essential to take necessary measures to reduce job stress and balance the planning of activities to manage personnel fatigue while improving the motivational system. Creating conventional conditions that align with the work environment through effective health and safety standards is also crucial. Addressing issues related to a lack of tolerance and neglect is important, as is ensuring that employees possess the necessary skills and comply with government regulations. Moreover, fostering a culture of commitment and motivation without deliberate delays in work can lead to better outcomes. Teaching self-control and self-discipline, as well as promoting selfreinforcement and self-punishment, can further discourage disobedience and hyperactivity among personnel.

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SAŽETAK

Istraživanje uloge ljudskih čimbenika u procjeni rizika podzemnih rudnika ugljena

U podzemnim rudnicima ugljena mogu se pojaviti specifične nesigurnosti. One dovode do sigurnosnih rizika te mogu rezultirati katastrofom i sigurnosnim problemima. Ljudski čimbenici povezani s nesigurnostima igraju ključnu ulogu u raznim industrijama, uključujući podzemnu eksploataciju ugljena. Primjerice, utječu na općenitu sigurnost, proizvodne procese, održavanje strojeva i produktivnost. Upravljanje rizikom jedna je od primarnih metoda za poboljšanje sigurnosti u podzemnim rudnicima ugljena. To je proces koji pomaže otkrivanju, procjeni i ublažavanju rizika i neizvjesnosti. Njegov je glavni cilj zaštititi resurse, poboljšati sigurnost i povećati učinkovitost putem donošenja odluka na bazi dobre informiranosti. Ovaj članak ispituje ulogu ljudskih čimbenika u procjeni rizika rudnika ugljena jer prvo klasificira ljudske čimbenike, a zatim se koristi metodom neizrazite tehnike za redoslijed prednosti prema sličnosti idealnomu rješenju (*Fuzzy Technique for Order of Preference by Similarity to Ideal Solution*, skraćeno Fuzzy-TOPSIS) za usporedbu procjene rizika podzemnih rudnika ugljena. TOPSIS metoda jest višekriterijska tehnika odlučivanja koja djeluje na temelju udaljenosti opcija od najboljih i najgorih rješenja. Ova metoda rangira opcije na temelju specifičnih kriterija i pomaže u odabiru optimalne opcije. Rezultati istraživanja ljudskih čimbenika pokazali su kako na procjenu rizika podzemnih rudnika najveći utjecaj ima nepažnja, nemar i rastresenost, s indeksom sličnosti od 0,6516, dok je najmanji utjecaj imala razina obrazovanja s indeksom sličnosti od 0,2871.

Ključne riječi:
ljudski čimbenici, stručna prosudba, procjena rizika, Fuzzy-TOPSIS, rudnici ugljena

Author's contribution

Abolghasem Ghasemi (PhD Candidate), compiler of all articles, author of the complete manuscript, and implementer of the research concept. **Mohammad Ataei** (Professor), idea generator and supervisor of this paper. **Farhang Sereshki** (Professor), idea generator and supervisor of this paper.