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Risk Analysis and Prioritization with AHP and Fuzzy TOPSIS Techniques in Surface Mines of Pakistan

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Abstract

Despite a decline in mining accidents and improvements in safety performance, the proportion of accidents in mines remains high in developing countries. Although underground mining is one of the most hazardous occupations, surface mining also carries multiple risks that receive comparatively less attention. In developing countries like Pakistan, research is focused mainly on fatal and serious accidents, often overlooking minor and near-miss accidents. This study assesses the risks of fatalities and injuries faced by occupational groups engaged in surface mining. For this purpose, an analytical hierarchy process is used to analyze fatalities data and Fuzzy TOPSIS for injuries data. It can be concluded that all occupational groups are exposed to fatalities and injuries risks due to various hazards. However, some activities are more prone to fatalities while others are to injuries. Laborers are most frequently involved in such accidents. Common risks such as falling rocks and slippage from the top affect all occupational groups equally. Incidents involving slippages from the tops result in more fatalities, whereas machinery-related risks lead to more injuries than fatalities. Hazards causing minor injuries are frequently overlooked in terms of prevention and control efforts until they lead to serious injuries/fatalities. It is suggested that every accident, regardless of severity, be reported and thoroughly analyzed regularly to minimize the recurrence of incidents. The essential measures for creating a safer mining environment include implementing appropriate mechanization, providing regular training to workers, enforcing the use of personal protective equipment, and strict adherence to mining laws.

1. Introduction

The mining industry is globally recognized for having one of the most hazardous, risky, and unsafe environments [1]. Risk is associated with different types of activities and machinery within the complex environment of mines, necessitating careful attention to mitigate the frequency and severity of accidents [2]. Successful industries focus not only on production but also on safety standards. Establishing standards is a crucial component of the risk and safety management system. It guides in the identification of undesirable risks and the understanding of their impacts [3]. The challenging issue in mining is to control the hazards and their associated risks. Controlling risks and enhancing safety relies on properly assessing hazards [4]. Mainly, policy decisions are made by considering and assessing the accident or incident data [3]. Risks analyzed from historical data can easily be illustrated, and are often considered trustworthy [5]. For this purpose, the potential hazards and their associated risks in the workplace need to be identified and prioritized according to the severity level of risks. Prioritization of the riskiest occupations is also essential for safety improvement in mines [6].

Common activities related to surface mining are drilling, blasting, cutting, excavating, loading, dumping, hauling, and crushing, etc., which require proper consideration due to associated risks that lead to accidents [7], [8]. Hit by fly rocks, misfires, fall of rock, slippage of foot, and fall from heights

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are the most common types of hazards in surface mines [6], [8], [9]. Most injuries resulting from accidents are investigated without considering the potential hazards, and these investigations into such losses and injuries often follow a deterministic approach [10]. Unsafe behavior and practices among workers, inadequate safety equipment and inappropriate apparatus, technical or unpredictable geological aspects, or a combination of these circumstances result in undesirable occupational health and safety consequences [11]. Eliminating these risks is a complex mining process due to uncertain geological conditions and environments [12]. Similarly, data availability, constraints, inadequate quality, and combining data from several systems running in different contexts are all significant challenges in data analysis [13]. Several risk assessment and evaluation methodologies are available to identify and assess the risks that result in accidents and provide an appropriate base for prioritizing risk factors [14]. The prioritization process helps reduce the severity and frequency of accidents by mitigating the most hazardous risk on a precedence basis [15]. Once the potential risks associated with hazards and risky occupations are identified, applying preventive and control measures becomes manageable and effective [6].

According to the Mines Act 1923 of Pakistan, a fatal accident involves at least one fatality. Serious accidents result in permanent disability or body part damage of a worker, while minor accidents entail injuries requiring less than twenty days of absence from work. One of the major issues in Pakistan is reporting and investigating fatal and serious accidents only, whereas minor and near-miss incidents are neither reported nor adequately documented (Figure 1). The primary cause of higher accident rates in specific occupations is non-evaluation of the accidents.The safety training is planned because some occupations are more prone to accidents than others. Similarly, accidents in underground mines and coal mines (underground and surface) are significantly high. However, the frequency of accidents in surface mines(other than coal) is also alarming in the country [16], [17].

The literature highlights that numerous studies are being conducted to evaluate underground mining accidents in Pakistan [18]–[22]. However, accidents in surface mines have received less attention in the country. This study evaluates the leading causes of accidents in surface mines by considering the two primary variables, occupations and risks, along with their correlations (detail is provided in the supplementary data). Accidents occur frequently in mines, and the proportion of occupations involved in these accidents is not the same. Similarly, some hazards are responsible for fatal accident causation more than others, while some cause injuries only [6], [16], [23]–[25]. Hazard investigations predominantly focus on fatal and serious accidents, neglecting less severe accidents. Consequently, specific hazards responsible for these accidents and the affected occupational groups are often disregarded, leading to a lack of proactive measures. Moreover, it is considered that specific occupational groups are disproportionately affected by the hazards associated with their respective job tasks. For instance, drillers are more susceptible to the risk inherent to drilling-related activities, whereas mechanics are particularly exposed to machinery-related risks.

This study determines a hierarchy of occupations with the highest susceptibility to fatalities and serious injuries. Additionally, it examines minor injuries and their underlying causes, which significantly impact the well-being of workers in the broader safety culture [26], [27]. Neglecting minor injuries can hinder safety progress, as they often reveal underlying issues that could lead to more severe incidents [28]. Recognizing and properly managing these incidents constitutes a fundamental aspect of the safety strategy within the mining industry. The study's outcomes offer valuable perspectives on the level of occupational risk in the mining sector, underscore the significance of addressing minor injuries, and illuminate their contribution to improving safety and averting incidents across all incident categories.

After a brief introduction, the paper is structured as follows. Section 2 conducts a literature analysis on the application of Multi-criteria Decision-Making (MCDM) methodologies in risk assessment and management, focusing on the surface mining industry. Section 3 begins with data gathering, and then presents the mathematical representation of selected approaches adapted to the nature of the data. These methods are then applied to the obtained data, considering the two data formats, each of which necessitates a unique analytical methodology. Section 4 thoroughly examines and discusses the results.

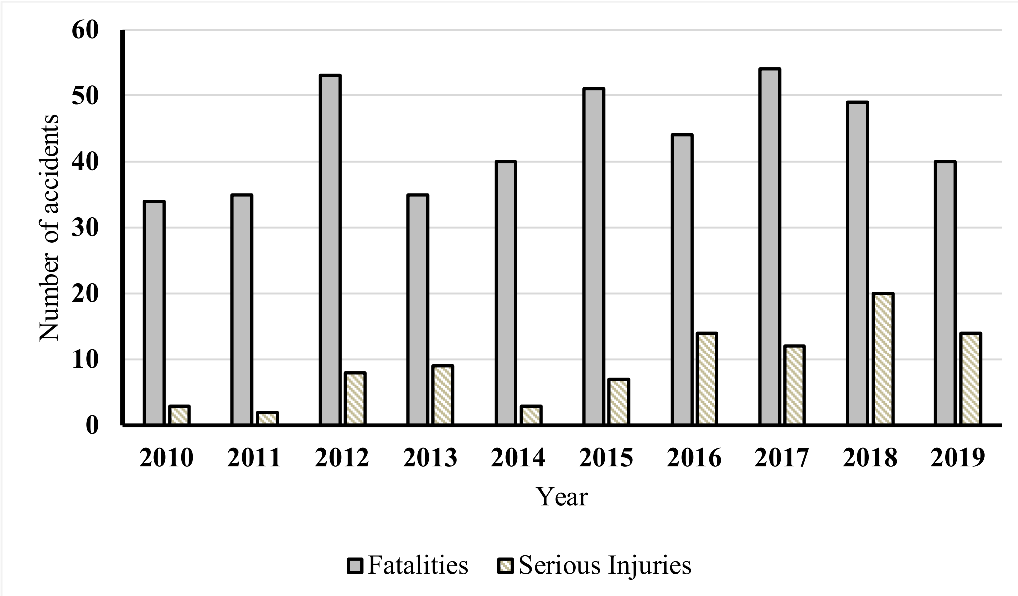

Figure 1. Fatalities and serious injuries reported in surface mines of Pakistan from 2010 to 2019.

2. Literature Review

Numerous research studies have been conducted to identify, evaluate, and prioritize risks in the workplace [29], [30]. The most extensively used decision-making procedures in research, engineering, and management are Multi-Criteria Decision Making (MCDM) methodologies [31]. MCDM techniques in risk assessment are based on human inputs and judgments [29], [32]. The common MCDM techniques are AHP, ANP, FTOPSIS, VIKOR, FRA, DEMATEL, and their fuzzy versions [29]. In the mining industry, Ersoy [25] applied AHP to analyze the weight of the risk of accident occurrence, the protective measures taken to reduce potential risks, and the number of accidents in marble quarries. Verma *et al.* [14] proposed a methodology to assess risks in the mining industry using AHP combined with the FRA approach to prioritize hazards based on the potential of associated risks. With the AHP method, Yasar *et al*. assessed the safety risk of several occupational groups employed in open pit mining by considering previous data on occupational accidents and various hazards associated with occupational groups [33]. A framework was suggested by Banda [34] for risk analysis established by using the AHP technique, questionnaire survey, and sensitivity analysis method for identifying volatile risks in mining projects. In developing pre-disaster management projects for the mineral industry, Spanidis *et al.*, used the expected value function, program evaluation review technique, and Monte Carlo simulation along with fuzzy AHP for risk assessment of natural hazards [35]. To investigate the operational strategies of the Iranian mining sector, Mohammad *et al.* [36] developed an integrated model that used the ANP technique for determining criterion weight, VIKOR for ranking, and SWOT (Strength, Weakness, Opportunities, and Threats) analysis. Mahdevari *et al*. applied FTOPSIS as a risk management tool to assess the hazards and possible risks to the health and safety of miners and support decision-making when selecting controls and solutions for underground coal [37]. Similarly, Gul & Ak applied a combined procedure established on occupational health and safety risk evaluation methodology in an underground copper-zinc mine by using the risk matrix method and fuzzy TOPSIS with trapezoidal sets and pythagorean fuzzy AHP for categorizing, identifying, and prioritizing hazards and risks [38]. By integrating the TOPSIS technique and the analytical hierarchy process, Spanidis selected an optimal restoration alternative with a low risk for continuous lignite surface mining [39]. Time series modeling was used to build a high-precision model by assessing the risk aspects, including frequency and severity indices [40]. Dong *et al*. adopted the fuzzy-grey correlation analysis technique and TOPSIS method to assess safety risks in Pb-Zn mines and reduce accidental loss and damage. They concluded that the fuzzy-grey method is more sensitive to risks [41]. Using fuzzy VIKOR and Shannon entropy, the environmental effects of mining activities were evaluated, and the most adversely affected environmental elements were found [42].

Similarly, Ataei and Norouzi [43] offered a methodical description of a sustainable development index based on the fuzzy DEMATEL method to assess the influencing environmental aspects of mining activities. Siahuei *et al.* [44] applied fuzzy sets with the Analytic Hierarchy Process (AHP) to investigate the management and evaluation of safety hazards in underground coal mines. Norouzi *et al.* [45] performed a risk assessment of fly rocks in surface mines utilizing Fuzzy FTA with DEMATEL and fuzzy ANP methods. Nehrii *et al.* [46] proposed a priority matrix for risk factors in longwall technological zones derived from expert surveys for each aspect within the matrix. They offered recommendations for technical and organizational safety measures to reduce miner accidents. FMEA was utilized by Esmailzadeh *et al*. [47] to assess and prioritize risks in quarries by considering probability, intensity, and risk detection.

Based on the literature review, it can be concluded that several MCDM methods are available, and each method has certain limitations and advantages. However, the majority of the researchers in the mining industry had extensively utilized the Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for risk assessment and management. AHP and TOPSIS are preferred due to their ability to address complex decision-making scenarios, prioritize risks, and provide structured approaches [48], [49]. The widespread adoption and application of these methodologies serve as evidence of their efficacy and importance in tackling challenges related to risks within the mining industry.

3. Research Methodology

The research methodology provides a description of the data collection procedures, techniques used for analysis, and their ways of application to achieve the research objectives, i.e. to assess and prioritize the occupational groups with the highest incidence of fatalities and injuries, and to identify the hazards associated with such incidents.

3.1. Data collection

For the collection of data regarding accident statistics in surface mines, the researchers visited every mine inspectorate department in the country. Data on fatal accidents and serious injuries is collected for a period spanning from 2010 to 2019. During site visits, comprehensive data on mine fatalities was gathered; however, injury data was insufficient. Injury information was gathered through a questionnaire administered to mine workers in surface mines, especially in sandstone, marble, and gypsum mines of Khyber Pakhtunkhwa and Punjab provinces of Pakistan, where accident frequency is higher than other surface mines. Occupations and hazards are divided into six identical groups to compare their data sets. Among 1500 distributed questionnaires, 1,368 were received, and the data was statistically analyzed using SPSS version 25.

3.2. Methods

To evaluate and rank the vulnerability of occupational groups to risks, the authors considered utilizing the well-established AHP and TOPSIS methodologies, which are frequently employed in risk assessment and its management. Detailed explanations of the basic theory and mathematical equations are presented in the subsequent sections.

3.2.1. Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) is a well-established approach to structure decision-making, and was initially developed by Thomas L. Saaty. It is widely applicable for systematical evaluation and ranking elements within complex scenarios. Conventional AHP uses crisp values as they are accurate and reduce the ambiguity provided by linguistic variables [50]. AHP assigns weights to risk parameters and provides the ability to calculate consistency level in decision-making by addressing the inadequacies in the computation of crisp numbers [29], [51]. The basic steps and equations involved in the AHP method are summarized below:

Step 1: Define decision hierarchy

The first step in AHP is defining the decision problem by creating a hierarchical structure.

Step 2: A pairwise comparison matrix (A-below) is constructed

$$A = (a_{ij})_{n*n} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \qquad (1)$$

where $a_{ij} > 0$; i and j = 1, 2, ... n; and ($a_{ij} = 1/a_{ji}$); "n" is the number of variables for evaluation. a_{ij} in equation 1, represents the relative significance of "i" with "j" factor, calculated with the assistance of experts and using Saaty's scale 9-point scale proposed by Saaty, ranging from 1 (having equal importance of both variables) to 9 (having extreme importance of one variable on another variable) [52].

Step 3: Normalization and relative criteria-weight

In order to assign relative weights to each variable, it is essential to normalize the comparison matrix by dividing each value by the sum of its respective column values [48], [53]. Then the criteria weight of the variable is obtained by taking the average of the row. The total sum of the criteria weights column is equal to 1.00 [42].

In AHP, λ_{max} is obtained by using Equation 2 :

$$AW = \lambda_{max} W \quad (2)$$

where A represents the pairwise comparison matrix, the largest eigenvalue of A is λ_{max}, and W is the normalized eigenvector corresponding to λ_{max} [54].

Step 4: Consistency ratio

AHP is also preferred for its ability to measure the consistency ratio (CR) in the judgment considered in the decision matrix. A satisfactory value for CR must be less than 0.1 [55]. The Consistency Ratio (CR) is calculated using Equation 3.

$$CR = \frac{CI}{RC} \quad (3)$$

where consistency indicator, CI = (λmax – n)/(n-1), with 'n' the number of variables in each criterion and λ_{max} is the maximum eigenvector in the matrix. Table 1 provides the Random Consistency (RC) index corresponding to the number of variables (n).

Table 1. Saaty Random Consistency (RC) index [56].

Number of variables (n)	1	2	3	4	5	6	7	8	9	10
Random consistency (RC)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.2.2. FTOPSIS method

The TOPSIS method, initially introduced by Hwang and Yoon in 1981 and extended by Chen *et al*. in 1992, serves as a viable Multiple Criteria Decision Making (MCDM) approach [57]. It is a valuable and practical approach for ranking and selecting a set of externally determined alternatives using distance measures [58]. The fuzzy TOPSIS method addresses the uncertainty and vagueness present in the data because, in some cases, using precise values is insufficient for representing decision problems in the real world. Mainly, it includes uncertain, imprecise, and subjective data, which introduces complexity and challenges in decision-making. Furthermore, fuzzy sets theory effectively acknowledges human opinion and judgment in ambiguity and lack of information [4], [59]. Additionally, this method is preferred for assessing probability and consequences using linguistic variables expressed by imprecise numbers. As a result, it reduces the inherent ambiguity and uncertainty that affect the decision-making process. The following are the mathematical formulas used in the FTOPSIS method:

The first step of the FTOPSIS method involves creating a matrix using data having likelihood and consequence values for each risk scenario. The linguistic variables are transformed into their fuzzy triangle numbers by assigning them likelihood (L) and consequence (C) on a pre-defined fuzzy scale consisting of three real values. The real values *l*, *m*, and *u* represent the lower, medium, and upper values respectively [60], [61]. Membership functions $\mu_{\tilde{M}}(x)$ for the triangular fuzzy numbers are defined in Equation 4.

$$\mu_{\tilde{M}}(x) = \begin{cases} (x-l)/(m-l) & if \quad l \leq x \leq m \\ (u-x)/(u-m) & if \quad m \leq x \leq u \\ 0 & otherwise \end{cases} \quad (4)$$

After assigning a fuzzy number, the normalization is processed to maintain fuzzy numbers in the range of 0 to 1 by using Equations 5 and 6.

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right); \; u_j^+ = max\, u_{ij} \; ; \; \forall_j^+ \quad (5)$$

$$\widetilde{r_{ij}} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right);\ l_j^- = \min l_j^-;\ \ \forall_j^- \quad (6)$$

The normalized fuzzy decision matrix is represented as:

$$R = [r_{ij}]_{m\times n} \quad (7)$$

where r_{ij} is the normalized value of $\tilde{x}_{ij} = (l_{ij},\ m_{ij},\ u_{ij})$. The weighted normalized matrix value $\widetilde{v_{ij}}$ is the product of weights ($\tilde{\omega}_j$) and the normalized fuzzy decision matrix $\widetilde{r_{ij}}$ is constructed as:

$$\tilde{v} = [\tilde{\omega}_j \widetilde{r_{ij}}] = [\widetilde{V_{ij}}]_{nx_j} \quad (8)$$

$$i = 1, 2, \ldots\ldots, m \quad j = 1, 2, \ldots\ldots n$$

In the next step, fuzzy positive ideal solution (A+) and negative ideal solution (A-) are obtained using Equations 9 and 10.

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \tilde{v}_3^+, \ldots\ldots\ldots \tilde{v}_n^+) = \{\max_i v_{ij} | (i = 1, 2, \ldots, m; j = 1, 2, \ldots., n\} \quad (9)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \ldots\ldots\ldots \tilde{v}_n^-) = \{\min_i v_{ij} | (i = 1, 2, \ldots, m; j = 1, 2, \ldots., n\} \quad (10)$$

The distances of each alternative from the fuzzy positive ideal solution (di+) and fuzzy negative ideal solution (di-) are calculated by Equations 11 and 12.

$$d_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^+\right) \quad (11)$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) \quad (12)$$

Distance between triangular fuzzy numbers of variables is calculated using the vertex method (Equation 13). Finally, each alternative is ranked with the help of the closeness coefficient index (CCi) in decreasing order using Equation 14.

$$d_v(\widetilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[\,(l_1 - l_2\,)^2 + (m - m_2\,)^2 + \,(u_1 - u_2\,)^2\,]|} \quad (13)$$

$$c_i = \left(\frac{\mathrm{d}_i^-}{d_i^+ + d_i^-}\right) \qquad \begin{matrix} C_i = 1 & {}_{if}A_i = A^+ \\ C_i = O & {}_{if}A_i = A^- \end{matrix} \quad (14)$$

With $d_i^+, d_i^- \geq 0$ and $C_i \in [0, 1]$

3.3. Application of proposed methods for analysis of fatalities and injuries data of surface mines

The fatalities and injuries data were analyzed individually, as the fatalities data is precise numerical values, and the injuries data is derived from the responses of workers collected through questionnaires, which reflects their perceptions of facing accidents. AHP and TOPSIS are preferred due to their ability to handle various decision-making scenarios, prioritize risks, and offer structured procedures. The conventional Analytic Hierarchy Process (AHP) is a well-established multi-criteria decision-making strategy that incorporates linguistic evaluations and is particularly effective when dealing with non-fuzzy data [62]. It simplifies the selection of the optimal choice by employing a weighted approach to compare different alternatives through pairwise evaluations. Considering the benefits, as mentioned earlier, of the traditional Analytic Hierarchy Process (AHP), it is selected for the analysis of fatalities data, and FTOPSIS is applied to the injuries data representing subjective assessments of accident likelihood and severity of the mine workers. Implementing FTOPSIS in this context seeks to address complex phenomena, uncertain data, and imprecise human behavior [38]. Additionally, the data utilized in this study is probabilistic in nature, considering the likelihood and consequences of the associated risks [15], [37]. Expert judgment on the data is collected from diverse individuals with at least ten years of experience in their respective fields, including academicians, mine inspectors, supervisors, and experienced mine workers, to ensure a comprehensive and reliable evaluation.

3.3.1. Analysis of fatalities data with AHP

The objective of using AHP is to design two levels of hierarchy. Level 1 comprises six factors of the occupational groups, and level 2 of the AHP hierarchy consists of thirty-six events generated from the interaction of each occupational group with every hazard group, as depicted in Figure 2. Specific codes were assigned based on the interaction of each occupation group with each hazard, as given in Table 1. The analysis is made to identify the occupation at high risk due to the particular hazards and for its timely control and prevention.

Table 2. Occupational groups encountering hazards groups.

Occupational groups	Hazards groups	Codes for risky events (Each occupational group encounters each hazard group)
1. Drillers (D)	1. Fall of rocks (F)	DF-11, DS-12, DB-13, DH-14, DMe-15, DE-16
2. Haulage workers (Hw)	2. Slippage from the top (S)	HwF-21, HwS-22, HwB-23, HwH-24, HwMe-25, HwO-26
3. Operators of excavators, dumpers, and loaders (O)	3. Blasting (B)	OF-31, OS-32, OB-33, OH-34, OMe-45, OE-46
4. Supervisors (S)	4. Haulage (H)	SF-41, SS-42, SB-43, SH-44, MMe-45, ME-46
5. Mechanics, electrician, and technician (M)	5. Machinery maintenance, etc. (Me)	MF-51, MS-52, MB-53, MH-54, MMe-55, ME-56
6. Labors (L)	6. Operating of excavator, dumper, and loader (E)	LF-61, LS-62, LB-63, LH-64, LMe-65, LE-66

After the construction of hierarchal order, based on the fatal accident data and the judgments experts, a pairwise comparison matrix for level 1 is constructed using Equation 1 to obtain rank for the risky occupations in the workplace. The suggestions of experts on the data are obtained using a 9-point scale proposed by Saaty, ranging from 1 having equal importance (here equal risk) of both variables to 9 having extreme importance of one variable on another [52]. The normalization of the comparison matrix was carried out, and the criteria weight of the variable was obtained by taking an average of the row. The summary of pairwise comparison of the matrix, normalization, and criteria weights is given in Table 3 (details in supplementary data). The value of λ_{max} is derived by using Equation 2, while the consistency ratio is determined by using Equation 3. These values are provided in the footnote of Table 3.

Table 3. Pairwise comparison matrix and risk ranking for occupational groups.

Occupational groups	Drillers	Haulage-workers	Operators	Supervisors	Mechanics	Labors	Criteria weights	Ranking
Drillers	1.0	3.0	4.0	5.0	6.0	0.25	0.22	2
Haulage workers	0.33	1.0	2.0	3.0	4.0	0.17	0.11	3
Operators	0.25	0.50	1.0	2.0	3.0	0.14	0.08	4
Supervisors	0.20	0.33	0.50	1.0	2.0	0.13	0.05	5
Mechanics	0.17	0.25	0.33	0.50	1.0	0.11	0.03	6
Labors	4.0	6.0	7.0	8.0	9.0	1.0	0.50	1

λ_{max} = 6.25; CI = 0.05; CR = 0.04

Similarly, six more pairwise matrices (detail is available in supplementary data) were formed by comparing each occupational group with hazard factors in level 2 of the hierarchy to prioritize the risk faced by the occupational group; results are given in column 4 of Table 4. The global weights were obtained by multiplying level 1 weights with level 2 weights, as shown in column 5 of Table 4, followed by the overall rank of the risk events. A ranking of risky events obtained from AHP reveals that laborers are the most affected occupational group and are more involved in fatalities due to falls of rocks and slippage from the top. The least involved group in fatalities is the mechanics group.

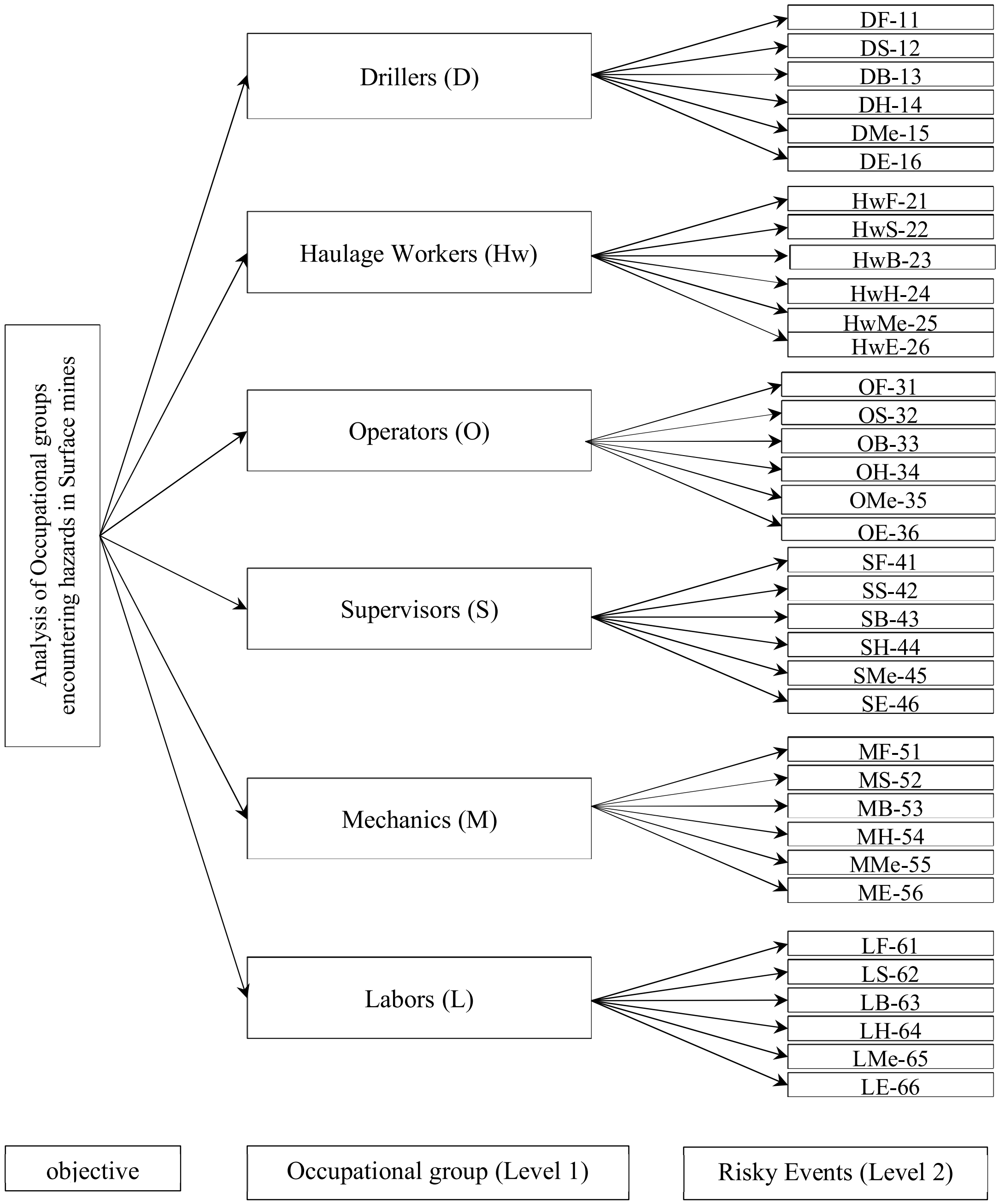

Figure 2. Hierarchy for risks ranking

Table 4. Global weights and overall ranking for fatalities data.

Occupational groups	Weights of level 1	Risky events	Weights of level 2	Global weights	Rank of risky events
Drillers	0.22	DF-11	0.46	0.011	18
		DS-12	0.26	0.101	3
		DB-13	0.12	0.057	4
		DH-14	0.03	0.026	11
		DMe-15	0.05	0.007	20
		DE-16	0.08	0.018	15
Haulage-Workers	0.11	HwF-21	0.26	0.003	26
		HwS-22	0.15	0.029	9
		HwB-23	0.06	0.017	16
		HwH-24	0.41	0.045	5
		HwMe-25	0.03	0.007	27
		HwE-26	0.08	0.009	28
Operators	0.08	OF-31	0.33	0.004	22
		OS-32	0.16	0.026	13
		OB-33	0.08	0.013	31
		OH-34	0.04	0.003	8
		OMe-35	0.05	0.006	23
		OE-36	0.33	0.026	32
Supervisors	0.05	SF-41	0.39	0.004	21
		SS-42	0.28	0.020	12
		SB-43	0.14	0.014	17
		SH-44	0.07	0.004	29
		SMe-45	0.08	0.007	30
		SE-46	0.05	0.003	33
Mechanics	0.03	MF-51	0.31	0.008	24
		MS-52	0.13	0.009	25
		MB-53	0.08	0.004	34
		MH-54	0.08	0.002	35
		MMe-55	0.26	0.002	36
		ME-56	0.13	0.004	19
Labors	0.08	LF-61	1.87	0.225	1
		LS-62	0.69	0.145	2
		LB-63	0.21	0.055	7
		LH-64	0.32	0.025	14
		LMe-65	2.89	0.015	6
		LE-66	0.42	0.035	10

3.3.2. Analysis of injuries data with FTOPSIS

In this study, all the potential risky activities with codes defined for fatalities were used for injuries data based on the likelihood and consequence of the events. In the analysis process, the selection of linguistic terms for likelihood and consequence was based on the preferences of the majority of experts for obtaining precision in results. The risk of encountering accidents by the occupational groups is taken as input constraint for likelihood obtained from questionnaire data and evaluated with the judgment of experts.The consequence of the accidents was derived from the accidents faced by the occupational groups through subjective judgment due to a lack of comprehensive accident records. FTOPSIS is applied to rank the risk by multiplication of likelihood (chances of the accidents encountered by occupational groups) with the consequence (impact of accidents commonly confronted by occupational groups). With the application of fuzzy theory, the risk constraints, i.e. likelihood and consequences, are expressed in fuzzy numbers relative to their linguistic variable. The likelihood is defined in linguistic terms (L-1 to L-9 given in Table 5), while the consequence is given in linguistic terms (C-1 to C-9) presented in Table 6. For the quantification of judgment, a nine-point triangular fuzzy numbers scale is utilized to extend liberty to the experts and decision- makers and to bring subjectivity to decision-making (Table 7) [60], [63].

The assigned linguistic terms for the likelihood of the risk and consequences of risk, along with their relative triangular fuzzy numbers (TFN), are given in Table 8. All the triangular fuzzy numbers lie in the range of closed interval 0 and 1; normalization is not required [37]. The risk for each factor is derived by multiplying triangular fuzzy numbers for likelihood with the triangular fuzzy numbers for consequence (Table 8).

Table 5. Linguistic term and description for likelihood.

Likelihood	Linguistic term	Description
L-1	Always	Very likely to face the occupational group
L-2	Almost always	Faced most commonly or regularly
L-3	Frequent	Faced numerously
L-4	Often	Faced often but less than normally
L-5	Sometimes	Faced occasionally
L-6	Possible	Chances to face but not very common
L-7	Seldom	Fewer chances to face
L-8	Improbable	Not likely to face
L-9	Never	No such experience or face never

Table 6. Linguistic Term and description for consequence.

Consequence	Linguistic term	Description
C-1	Catastrophic	Most fatalities arise from the event
C-2	Critical	More chances of fatality occurrence
C-3	Severe	Fatality or disability/severe injuries
C-4	High	Injuries need more than twenty days off work
C-5	Medium-High	Injury needs for four to twenty days off work
C-6	Medium	Minor injury with less than three days off work
C-7	Low	Minor injury with no off-work required
C-8	Minor	Near-miss (narrow escape)
C-9	Negligible	Negligible

Table 7. 9-Points linguistic scale with corresponding Triangular Fuzzy numbers [60], [63].

Linguistic scale		Triangular fuzzy scale
Consequence	Linguistic term	TFNs (l, m, u)
L-1	C-1	(0.8, 0.9, 1)
L-2	C-2	(0.7, 0.8, 0.9)
L-3	C-3	(0.6, 0.7, 0.8)
L-4	C-4	(0.5, 0.6, 0.7)
L-5	C-5	(0.4, 0.5, 0.6)
L-6	C-6	(0.3, 0.4, 0.5)
L-7	C-7	(0.2, 0.3, 0.4)
L-8	C-8	(0.1, 0.2, 0.3)
L-9	C-9	(0.0, 0.1, 0.2)

The Fuzzy positive ideal solution (0.42, 0.56, 0.72) and fuzzy negative ideal solution FNIS (0.01, 0.04, 0.09) are computed using equations (9) & (10), respectively. The distance of each risk factor from FPIS (di+) and FNIS (di-) is obtained by using equations (11) & (12), respectively. The defuzzified value is obtained with the vertex method using equation 13. Finally, the closeness coefficient(Ci) is calculated with Equation 14, and the risk factor is ranked according to their Ci index. As the ranking of factors is based on their risk, the factors having Ci close to 1 are considered high-risk factors, while factors having Ci close to 0 are considered low-risk factors. Analysis of data with FTOPSIS in Table 8 shows that the riskiest occupational group is laborers, who are affected mainly by the fall of rocks and slippage from the top. The next risky occupational group is drillers, which are affected mainly by blasting, fall of rocks, and slippage from the top. Similarly, other occupational groups are also facing various types of risks.

Table 8. Risk calculation and ranking of injuries data.

Risky events	L	C	TFN (L)	TFN (C)	TFN (L x C)	di+	di-	Ci	Rank
DF-11	L5	C2	(0.4, 0.5, 0.6)	(0.7, 0.8, 0.9)	(0.28,0.4,0.54)	0.161	0.284	0.64	5
DS-12	L5	C3	(0.4, 0.5, 0.6)	(0.6, 0.7, 0.8)	(0.24, 0.35, 0.48)	0.211	0.234	0.52	6
DB-13	L4	C2	(0.5, 0.6, 0.7)	(0.7, 0.8, 0.9)	(0.35, 0.48, 0.63)	0.08	0.365	0.82	3
DH-14	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
DM-15	L6	C7	(0.3, 0.4, 0.5)	(0.2, 0.3, 0.4)	(0.06, 0.12, 0.2)	0.445	0.084	0.16	18
DE-16	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
HwF-21	L6	C3	(0.3, 0.4, 0.5)	(0.6, 0.7, 0.8)	(0.18, 0.28, 0.4)	0.282	0.163	0.37	9
HwS-22	L5	C4	(0.4, 0.5, 0.6)	(0.5, 0.6, 0.7)	(0.2, 0.3, 0.42)	0.262	0.183	0.41	7
HwB-23	L8	C6	(0.1, 0.2, 0.3)	(0.3, 0.4, 0.5)	(0.03, 0.08, 0.15)	0.486	0.041	0.08	24
HwH-24	L4	C3	(0.5, 0.6, 0.7)	(0.6, 0.7, 0.8)	(0.3, 0.42, 0.56)	0.141	0.304	0.68	4
HwM-25	L7	C8	(0.2, 0.3, 0.4)	(0.1, 0.2, 0.3)	(0.02, 0.06, 0.12)	0.507	0.062	0.11	20
HwE-26	L6	C7	(0.3, 0.4, 0.5)	(0.2, 0.3, 0.4)	(0.06, 0.12, 0.2)	0.445	0	0	35
OF-31	L5	C4	(0.4, 0.5, 0.6)	(0.5, 0.6, 0.7)	(0.2, 0.3, 0.42)	0.262	0.183	0.41	7
OS-32	L6	C5	(0.3, 0.4, 0.5)	(0.4, 0.5, 0.6)	(0.12, 0.2, 0.3)	0.363	0.082	0.18	15
OB-33	L7	C8	(0.2, 0.3, 0.4)	(0.1, 0.2, 0.3)	(0.02, 0.06, 0.12)	0.507	0.062	0.11	20
OH-34	L5	C7	(0.4, 0.5, 0.6)	(0.2, 0.3, 0.4)	(0.08, 0.15, 0.24)	0.414	0.031	0.07	25
OM-35	L6	C7	(0.3, 0.4, 0.5)	(0.2, 0.3, 0.4)	(0.06, 0.012, 0.2)	0.445	0	0	35
OE-36	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
SF-41	L6	C3	(0.3, 0.4, 0.5)	(0.6, 0.7, 0.8)	(0.18, 0.28, 0.4)	0.282	0.163	0.37	9
SS-42	L6	C4	(0.3, 0.4, 0.5)	(0.5, 0.6, 0.7)	(0.15, 0.24, 0.35)	0.323	0.122	0.28	12
SB-43	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
SH-44	L7	C8	(0.2, 0.3, 0.4)	(0.1, 0.2, 0.3)	(0.02, 0.06, 0.12)	0.507	0.062	0.11	20
SM-45	L8	C7	(0.1, 0.2, 0.3)	(0.2, 0.3, 0.4)	(0.02, 0.06, 0.12)	0.507	0.062	0.11	20
SE-46	L8	C8	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(0.01, 0.04, 0.09)	0.528	0.084	0.14	19
MeF-51	L6	C4	(0.3, 0.4, 0.5)	(0.5, 0.6, 0.7)	(0.15, 0.24, 0.35)	0.323	0.122	0.28	12
MeS-52	L7	C5	(0.2, 0.3, 0.4)	(0.4, 0.5, 0.6)	(0.08, 0.15, 0.24)	0.414	0.031	0.07	25
MeB-53	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
MeH-54	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
MeM-55	L5	C6	(0.4, 0.5, 0.6)	(0.3, 0.4, 0.5)	(0.12, 0.2, 0.3)	0.363	0.082	0.18	15
MeE-56	L7	C7	(0.2, 0.3, 0.4)	(0.2, 0.3, 0.4)	(0.04, 0.09, 0.16)	0.476	0.031	0.06	28
LF-61	L3	C2	(0.6, 0.7, 0.8)	(0.7, 0.8, 0.9)	(0.42, 0.56, 0.72)	0	0.445	1	1
LS-62	L3	C2	(0.6, 0.7, 0.8)	(0.7, 0.8, 0.9)	(0.35, 0.48, 0.63)	0.08	0.365	0.82	2
LB-63	L5	C5	(0.4, 0.5, 0.6)	(0.4, 0.5, 0.6)	(0.16, 0.25, 0.36)	0.313	0.132	0.3	11
LH-64	L4	C6	(0.5, 0.6, 0.7)	(0.3, 0.4, 0.5)	(0.15, 0.24, 0.35)	0.323	0.122	0.28	12
LM-65	L5	C7	(0.4, 0.5, 0.6)	(0.2, 0.3, 0.4)	(0.08, 0.15, 0.24)	0.414	0.031	0.07	25
LEx-66	L6	C5	(0.3, 0.4, 0.5)	(0.4, 0.5, 0.6)	(0.12, 0.2, 0.3)	0.363	0.082	0.18	15

4. Discussion

This study used the fatal accidents and injuries data to determine which occupational groups in surface mines are most commonly exposed to the risks associated with mine activities and to establish comparisons between the hazards resulting in the highest fatalities and injuries. Risk ranking is performed not for exact quantification and estimation but to define risk level for control and remediation [37]. AHP and FTOPSIS prioritize occupational groups based on their risk of facing potential hazards that result in fatalities or injuries. This approach helps to identify the risks that need to be reduced and the occupational groups that should be prioritized for specific safety training related to those hazards. The ranking of the two types of data is compared in Table 9, revealing that almost all occupational groups are involved in accidents. Some occupations, such as labor, are comparatively more affected than others. Moreover, some of the hazards are more detrimentally effective, such as rock falls, which are corroborated by various researchers [6] [64]–[67]. Further, Table 9 also depicts that all those factors associated with more risk of injuries than fatalities are comparatively less considered for control or prevention purposes.

When the driller group was evaluated for hazards in terms of fatalities and injuries, it was found that they were among the most affected groups. The drillers faced more fatalities than injuries due to slippage from the top of steeply inclined faces, haulage, and excavator-related hazards. However, they have received more injuries from falls of rocks, blasting, and machinery-related hazards. The drilling site needs to be appropriately inspected for geological concerns, stability problems, etc., to reduce accidents experienced by the drillers [68]. Similarly, haulage workers are likely to encounter more fatalities than injuries due to blasting and excavator-related hazards; however, they have faced more injuries than fatalities from the other hazards, as depicted in Table 9. Haulage workers are also more affected by the haulage-related hazards. Therefore, a haulage worker must be a skilled driver, have completed the required safety training, be familiar with the mining site and be able to report unsafe situations before starting work in a mine.

The occupational group of machinery operators, including excavators, dumpers, and loaders, face more fatalities than injuries due to machinery-related hazards and slippage from the top. The operator group is more affected by falls of rocks for injuries and haulage-related hazards for fatalities than machinery and excavator-related hazards. Comparatively, operators are considered low-risk occupations. In addition, adequate training in identifying hazards can assist operators in avoiding accidents. Supervisors are also confronting fatalities and injuries, which reflect the hazardous conditions of the mines. Due to their lack of participation in physical work activities, supervisors are generally involved in injuries, but their involvement is still concerning and needs comprehensive safety training. Since mechanics and technicians spend less time in the mining sites, they are less likely to encounter accidents. However, rock falls are so prevalent in mines that they also affect and cause injuries. Mechanics and technicians must be trained to recognize and report hazards to avoid accidents.

Further, mechanical, and technical problems must be adequately addressed since they can occasionally lead to severe accidents. Among the occupational groups, laborers are the most affected group by almost all hazards. Labors must be trained to comprehend, identify, and safeguard themselves from all mine hazards. Comprehensive accident documentation and evaluation contribute to reducing accident occurrences, thereby enhancing the prevention of fatalities and injuries [6], [69]. Most of the accidents are due to a lack of mechanization in mines, steepgrounds, narrow haul roads, and violation of law [8]. Proper consideration of all hazards associated with high to low risk and occupation at high to low risk are essential for safety improvement.

Table 9. Comparison of ranking of fatalities and injuries data.

Risky events	Ranking of injuries data	Ranking of fatalities data	More risk of fatalities or injuries
DF-11	5	18	Injuries
DS-12	6	3	Fatalities
DB-13	3	4	Injuries
DH-14	28	11	Fatalities
DM-15	18	20	Injuries
DE-16	28	15	Fatalities
HwF-21	9	26	Injuries
HwS-22	7	9	Injuries
HwB-23	24	16	Fatalities
HwH-24	4	5	Injuries
HwM-25	20	27	Injuries
HwE-26	35	28	Fatalities
OF-31	7	22	Injuries
OS-32	15	13	Fatalities
OB-33	20	31	Injuries
OH-34	25	8	Fatalities
OM-35	35	23	Fatalities
OE-36	28	32	Injuries
SF-41	9	21	Injuries
SS-42	12	12	Fatalities
SB-43	28	17	Fatalities
SH-44	20	29	Injuries
SM-45	20	30	Injuries
SE-46	19	33	Injuries
MeF-51	12	24	Injuries
MeS-52	25	25	Fatalities

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Table 9. Comparison of ranking of fatalities and injuries data.

Risky events	Ranking of injuries data	Ranking of fatalities data	More risk of fatalities or injuries
MeB-53	28	34	Injuries
MeH-54	28	35	Injuries
MeM-55	15	36	Injuries
MeE-56	28	19	Fatalities
LF-61	1	1	Fatalities
LS-62	2	2	Fatalities
LB-63	11	7	Fatalities
LH-64	12	14	Injuries
LM-65	25	6	Fatalities
LEx-66	15	10	Fatalities

5. Conclusions

This article presents the findings of a study designed to determine priorities for risk to improve safety in workplaces, especially in surface mines in Pakistan. Based on the ranking with analytical hierarchy process for fatalities data and fuzzy TOPSIS for injuries data, created on human perception and experience, it is concluded that all occupational groups are frequently facing fatalities and injuries in surface mines. Although fatalities and serious injuries have been reported, still more attention is required to reduce fatalities. Minor injuries and near misses are also frequently experienced by workers but are not recorded or reported to the concerned departments. It is essential to focus on the root causes of injuries to eliminate them, reducing injuries and fatalities. It is also identified that labor is the most afflicted group in terms of both fatalities and injuries, while mechanics are the least. The higher risks are associated with the fall of rocks and slippage from the top. Specific hazards are more likely to cause injuries, but they are frequently ignored in terms of management as they are not directly or significantly associated with mine fatalities. Management of hazards and associated risks in the mining industry is essential, not only for reducing fatalities and injuries but also for reducing other financial losses. The mines need to be mechanized, personal protective equipment should be mandatory in mines, and safety-related laws should be enforced. In addition, the workers should be provided with specific safety training according to their environments. It is recommended that the root causes of accidents that result in fatalities and injuries be extensively investigated.

List of Acronyms

AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
DEMATEL	Decision-Making Trial and Evaluation Laboratory
FRA	Fuzzy Reasoning Approach
FTA	Fault Tree Analysis
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	Vlsekriterijumska Optimizacija I Kompromisno Resenje

References

[1]. Verma, S., & Chaudhari, S. (2016). Highlights from the literature on risk assessment techniques adopted in the mining industry: A review of past contributions, recent developments and future scope. *International Journal of Mining Science and Technology*. 26 (4), 691–702.

[2]. Badri, A., Nadeau, S., & Gbodossou, A. (2013). A new practical approach to risk management for underground mining project in Quebec. *Journal of Loss Prevention in the Process Industries*. 26 (6), 1145–1158.

[3]. Kumar, P., Gupta, S., Agarwal, M., & Singh, U. (2016). Categorization and standardization of accidental risk-criticality levels of human error to develop risk and safety management policy. *Safety Science*. 85 88–98.

[4]. Gürcanli, G.E., & Müngen, U. (2009). An occupational safety risk analysis method at construction sites using fuzzy sets. *International Journal of Industrial Ergonomics*. 39 (2), 371–387.

[5]. Sari, M., Karpuz, C., & Duzgun, S. (2009). Stochastic modeling of accident risks associated with an underground coal mine in Turkey,.

[6]. Stemn, E. (2019). Analysis of Injuries in the Ghanaian Mining Industry and Priority Areas for Research. *Safety and Health at Work*. 10 (2), 151–165.

[7]. Bae, H., Simmons, D.R., & Polmear, M. (2021). Promoting the Quarry Workers ’ Hazard Identification Through Formal and Informal Safety Training. *Safety and Health at Work*. 12 (3), 317–323.

[8]. Sherin, S., Raza, S., & Ahmad, I. (2023). Conceptual Framework for Hazards Management in the Surface Mining Industry — Application of Structural Equation Modeling. *Safety*. 9 (2:31),.

[9]. Ministry of Labour (2015). Mining Health , Safety and Prevention Review. *Final Report (Vol.1) Ontario*, 66. http://www.labour.gov.on.ca/english/hs/pdf/mining_progress_report.pdf.

[10]. Sari (2002). Risk Assessment Approach on Underground Coal Mine Safety Analysis, The Graduate School of Natural and Applied Science of The Middle East Technical University.

[11]. ICMM (2012). Overview of leading indicators for occupational health and safety in mining. *International Council on Metals and Mining*. (November), 55.

[12]. Kenzap, S.A., & Kazakidis, V. N. (2013). Operating risk assessment for underground metal mining systems: Overview and discussion. *International Journal of Mining and Mineral Engineering*. 4 (3), 175–200.

[13]. Nouri Gharahasanlou, A., Ataei, M., Khalokakaie, R., Barabadi, A., & Einian, V. (2017). Risk based maintenance strategy: a quantitative approach based on time-to-failure model. *International Journal of System Assurance Engineering and Management*. 8 (3), 602–611.

[14]. Verma, S., & Chaudhri, S. (2014). Integration of fuzzy reasoning approach (FRA) and fuzzy analytic hierarchy process (FAHP) for risk assessment in mining industry. *Journal of Industrial Engineering and Management*. 7 (5), 1347–1367.

[15]. Koulinas, G.K., Demesouka, O.E., Marhavilas, P.K., Vavatsikos, A.P., & Koulouriotis, D.E. (2019). Risk assessment using fuzzy TOPSIS and PRAT for sustainable engineering projects. *Sustainability (Switzerland)*. 11 (3), 15.

[16]. Sherin, S. (2022). Development of Conceptual Framework for Managing Workplace Hazards in Surface Mining Industry of Pakistan (Ph.D Thesis)., Univeristy of Engineering and Technology, Peshawar.

[17]. Ghasemi, E., Ataei, M., Shahriar, K., Sereshki, F., Jalali, S.E., & Ramazanzadeh, A. (2012). Assessment of roof fall risk during retreat mining in room and pillar coal mines. *International Journal of Rock Mechanics and Mining Sciences*. 54 (September), 80–89.

[18]. Shahani, N.M., Sajid, M.J., Zheng, X., Jiskani, I.M., Brohi, M.A., Ali, M., et al. (2019). Fault tree analysis and prevention strategies for gas explosion in underground coal mines of Pakistan. *Mining of Mineral Deposits*. 13 (4), 121–128.

[19]. Shah, K.S., Khan, M.A., Khan, S., Rahman, A., Khan, N.M., & Abbas, N. (2020). Analysis of Underground Mining Accidents at Cherat Coalfield, Pakistan. *International Journal of Economic and Environmental Geology*. 11 (1), 113–117.

[20]. Shahani, N.M., Sajid, M.J., Jiskani, I.M., Ullah, B., & Qureshi, A.R. (2020). Comparative Analysis of Coal Miner's Fatalities by Fuzzy Logic. *Journal of Mining and Environment*, *12 (1)*, 77-87.

[21]. Khan, S., Shah, K.S., Abbas, N., Rahman, A., & Khan, N.M. (2021). Analysis and Forecast of Mining Fatalities in Cherat Coal Field, Pakistan. *International Journal of Economic and Environmental Geology, 11 (4)*, 22–26.

[22]. Ayaz, M., Jehan, N., Nakonieczny, J., Mentel, U., & Uz Zaman, Q. (2022). Health costs of environmental pollution faced by underground coal miners: Evidence from Balochistan, Pakistan. *Resources Policy*. *76*. 1-10.

[23]. Rahimdel, M.J. (2021). Injury analysis of Iran's mining workplaces. *The Mining-Geology-Petroleum Engineering Bulletin*, *36 (1),* 15–23.

[24]. Esmailzadeh, A., Haghshenas, S.S., Mikaeil, R., Guido, G., Faradonbeh, R.S., Azghan, R.A., et al. (2022). Risk Assessment in Quarries using Failure Modes and Effects Analysis Method (Case study: West-Azerbaijan Mines). *Journal of Mining and Environment*, *13* (3), 715–725.

[25]. Abebil, F., Tefera, Y., Tefera, W., Kumie, A., Mulugeta, H., & Kassie, G. (2023) Nonfatal Occupational Injuries Among Artisanal and Small-scale Gold Mining Workers in Ethiopia. *Environmental Health Insights*, *17,* 1–18.

[26]. Nasarwanji, M.F., & Sun, K. (2019). Burden associated with nonfatal slip and fall injuries in the surface stone, sand, and gravel mining industry. *Safety Science, 120,* 625–635.

[27]. Ajith, M.M., Ghosh, A.K., & Jansz, J. (2020). Risk Factors for the Number of Sustained Injuries in Artisanal and Small-Scale Mining Operation. *Safety and Health at Work*, *11 (1)*, 50–60.

[28]. Mottahedi, A., Sereshki, F., Ataei, M., Nouri Qarahasanlou, A., & Barabadi, A. (2021). Resilience analysis: A formulation to model risk factors on complex system resilience. *International Journal of System Assurance Engineering and Management, 12 (5)*, 871–883.

[29]. Gul, M. (2018). A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. *Human and Ecological Risk Assessmen*t, *24 (7)*, 1723–1760.

[30]. Sitorus, F., Cilliers, J.J., & Brito-Parada, P.R. (2019). Multi-criteria decision making for the choice problem in mining and mineral processing : Applications and trends, *121*, 393–417.

[31]. Alguliyev, R.M.O., Aliguliyev, R.M., & Mahmudova, R.S. (2015). Multicriteria Personnel Selection by the Modified Fuzzy VIKOR Method. The *Scientific World Journal*, *2015*, 16.

[32]. Mardani, A., Jusoh, A., & Zavadskas, E.K. (2015). Fuzzy multiple criteria decision-making techniques and applications - Two decades review from 1994 to 2014. *Expert Systems with Applications*, *42 (8)*, 4126–4148.

[33]. Kasap, Y., & Subasi, E. (2017). Risk assessment of occupational groups working in open pit mining : Analytic Hierarchy Process. *Journal of Sustainable Mining Journal*, *16,* 38–46.

[34]. Banda, W. (2019). An integrated framework comprising of AHP, expert questionnaire survey and sensitivity analysis for risk assessment in mining projects. *International Journal of Management Science and Engineering Management, 14 (3),* 180–192.

[35]. Spanidis, P.M., Roumpos, C., & Pavloudakis, F. (2021). A fuzzy-ahp methodology for planning the risk management of natural hazards in surface mining projects. *Sustainability (Switzerland)*, *13 (4)*, 1–23.

[36]. Fouladgar, M.M., Yakhchali, S.H., Yazdani-Chamzini, A., & Basiri, M.H. (2011). Evaluating the strategies of the Iranian mining sector using a integrated model. 2011 Int. Conf. Financ. Manag. Econ. IACSIT Press. Singapore., IPEDR vol.11 (2011). IACSIT Press, Singapore, 58–63.

[37]. Mahdevari, S., Shahriar, K., & Esfahanipour, A. (2014). Human health and safety risks management in underground coal mines using fuzzy TOPSIS. *Science of the Total Environment*. *488–489 (1)*, 85–99.

[38]. Gul, M., & Ak, M.F. (2018). A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. *Journal of Cleaner Production*, *196,* 653–664.

[39]. Spanidis, P.M., Roumpos, C., & Pavloudakis, F. (2020). A Multi-criteria approach for the evaluation of low risk restoration projects in continuous surface lignite mines. *Energies*, *13 (9)*, 22.

[40]. Mohseni, M. ,& Ataei, M. (2016). Risk prediction based on a time series case study: Tazareh coal mine. *Journal of Mining & Environment*, *7 (1),* 127–134.

[41]. Dong, G., Wei, W., Xia, X., Woźniak, M., & Damaševičius, R. (2020). Safety risk assessment of a Pb-Zn mine based on fuzzy-grey correlation analysis. *Electronics (Switzerland)*, *9 (130)*, 20.

[42]. Tabasi, S. & Kakha, G.H., (2021). An application of Fuzzy-VIKOR method in environmental impact assessment of the Boog mine southeast of Iran. *International Journal of Engineering Transactions C: Aspects*, *34 (6),* 1548–1559.

[43]. Ataei, M. & Norouzi Masir, R. (2020). A fuzzy DEMATEL based sustainable development index (FDSDI) in open pit mining – a case study. *The Mining-Geology-Petroleum Engineering Bulletin*. *35 (1)*, 1–11.

[44]. Siahuei, M.R.A., Ataei, M., Rafiee, R., & Sereshki, F. (2021). Assessment and management of safety risks through hierarchical analysis in fuzzy sets type 1 and type 2: A case study (faryab chromite underground mines). *Rudarsko-Geološko-Naftni Zbornik (The Mining-Geology-Petroleum Engineering Bulletin)*, *36 (3),* 1–17.

[45]. Norouzi Masir, R., Ataei, M., & Motahedi, A. (2021). Risk assessment of Flyrock in Surface Mines using a FFTA-MCDM Combination. *Journal of Mining and Environment*, *12 (1)*, 191–203.

[46]. Nehrii, S., Nehrii, T., Zolotarova, O., Glyva, V., Surzhenko, A., & Tykhenko, O. (2022). Determining Priority of Risk Factors in Technological Zones of Longwalls. *Journal of Mining and Environment*, *13 (3)*, 751–765.

[47]. Esmailzadeh, A., Haghshenas, S.S., Mikaeil, R., Guido, G., & Faradonbeh, R.S. (2022). Risk Assessment in Quarries using Failure Modes and Effects Analysis Method (Case study : West-Azerbaijan Mines). *Journal of Mining and Environment (JME), 13(3),* 715–725.

[48]. Vaidya, O.S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research*, *169*, 1–29.

[49]. Nezarat, H., Sereshki, F., & Ataei, M. (2015). Ranking of geological risks in mechanized tunneling by using Fuzzy Analytical Hierarchy Process (FAHP). *Tunnelling and Underground Space Technology*, *50*, 358–364.

[50]. Mulubrhan, F., Mokhtar, A.A., & Muhammad, M. (2014). Comparative analysis between fuzzy and traditional analytical hierarchy process. *MATEC Web of Conferences*, *13*, 01006.

[51]. Ishizaka, A. (2014). Comparison of fuzzy logic, AHP, FAHP and hybrid fuzzy AHP for new supplier selection and its performance analysis. *International Journal of Integrated Supply Management*, *9 (1/2)*, 1–22.

[52]. Dano, U.L. (2018). Improving Traffic Safety Towards Sustainable Built Environment in Dammam City, Saudi Arabia. *IOP Conference Series: Earth and Environmental Science, 151(1)*, 8.

[53]. Kil, S.H., Lee, D.K., Kim, J.H., Li, M.H., & Newman, G. (2016) Utilizing the analytic hierarchy process to establish weighted values for evaluating the stability of slope revegetation based on hydroseeding applications in South Korea. *Sustainability (Switzerland)*. 8 (1), 1–17.

[54]. Sevkli, M., Zaim, S., Turkyilmaz, A., & Satir, M. (2010). An application of fuzzy TOPSIS method for supplier selection. *FUZZ-IEEE 2010, IEEE*

International Conference on Fuzzy Systems, Barcelona, Spain, 18-23 July 2010, Proceedings.

[55]. Pachemska, T.A.-, Lapevski, M., & Timovski, R. (2014). Analytical Hierarchical Process (AHP) method application in the process of selection and evaluation. in: Proceedings. Gabrovo International Sci. Conf. “UNITECH”. 21-22 November 2014, 373–380.

[56]. Alyamani, R. & Long, S. (2020). The application of fuzzy analytic hierarchy process in sustainable project selection. *Sustainability (Switzerland) 12(20*), 1–16.

[57]. Assed N. Haddad, Bruno B. F. da Costa, Larissa S. de Andrade, A.H. and C.A.P.S. (2021). Application of Fuzzy-Topsis Method in Supporting Supplier Selection with focus on HSE Criteria : A Case Study in the Oil and Gas Industry. *MDPI - Infrastructures*, *6 (105)*, 1–16.

[58]. Bakioglu, G. & Atahan, A.O. (2021). AHP integrated TOPSIS and VIKOR methods with Pythagorean fuzzy sets to prioritize risks in self-driving vehicles. *Applied Soft Computing*, *99,* 106948.

[59]. Mathew, M., Chakrabortty, R.K., & Ryan, M.J. (2020). A novel approach integrating AHP and TOPSIS under spherical fuzzy sets for advanced manufacturing system selection. *Engineering Applications of Artificial Intelligence*, 96, 103988.

[60]. Habibi, A., Jahantigh, F.F., & Sarafrazi, A. (2015). Fuzzy Delphi Technique for Forecasting and Screening Items. *Asian Journal of Research in Business Economics and Management*, *5 (2)*, 130--143.

[61]. Balli, S., & Korukoğlu, S. (2009). Operating system selection using fuzzy AHP and topsis methods. *Mathematical and Computational Applications*, *14 (2)*, 119–130.

[62]. Özdağoğlu, A. (2007). Comparison of AHP and Fuzzy AHP for the Multi-Criteria Decision Making Processes with Linguistic Evaluations. *İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi*, *6 (11)*, 65-85.

[63]. Zhou, X. & Lu, M. (2012). Risk Evaluation of Dynamic Alliance Based on Fuzzy Analytic Network Process and Fuzzy TOPSIS. *Journal of Service Science and Management*, *5 (3)*, 230–240.

[64]. Ural, S., & Demirkol, S. (2008). Evaluation of occupational safety and health in surface mines. *Safety Science*, 46, 1016–1024.

[65]. Sanmiquel, L., Freijo, M., Edo, J., & Rossell, J.M. (2010) Analysis of work related accidents in the Spanish mining sector from 1982-2006. *Journal of Safety Research*, 4*1 (1)*, 1–7.

[66]. Coleman, P.J., Brune, J., & Martini, L. (2010). Characteristics of the top five most frequent injuries in United States mining operations, 2003-2007. *Trans Soc Min Metal Explor*.,*326*, 61–70.

[67]. Sanmiquel, L., Bascompta, M., Rossell, J.M., And, H.F.A., & Guash, E. (2018). Analysis of Occupational Accidents in Underground and Surface Mining in Spain Using Data-Mining Techniques. *International Journal of Environmental Research and Public Health, 15*, 1–11.

[68]. Drechsler, B., Hinton, J.J., & Walle, M. (2010). An Occupational Safety Health System for Small Scale Mines in Rwanda. http://www.bgr.bund.de/EN/Themen/Min_rohstoffe/Downloads/Rwanda-Reportsmall- scale-mines.pdf.

[69]. Tetzlaff, E., Eger, T., Pegoraro, A., Dorman, S., & Pakalnis, V. (2020). Analysis of recommendations from mining incident investigative reports: A 50-year review. *Safety*. 6 (1), 1–15.

تحلیل ریسک و اولویت‌بندی با تکنیک‌های AHP و فازی TOPSIS در معادن سطحی پاکستان

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چکیده:

علیرغم کاهش تصادفات معدنی و بهبود عملکرد ایمنی، نسبت تصادفات در معادن در کشورهای در حال توسعه همچنان بالاست. اگرچه معدنکاری زیرزمینی یکی از خطرناک‌ترین مشاغل است، معدنکاری سطحی نیز خطرات متعددی را به همراه دارد که نسبتاً کمتر مورد توجه قرار می‌گیرد. در کشورهای در حال توسعه مانند پاکستان، تحقیقات عمدتاً بر تصادفات مرگبار و جدی متمرکز است که اغلب از تصادفات جزئی و نزدیک نادیده گرفته می‌شود. این مطالعه خطرات تلفات و جراحات پیش روی گروه‌های شغلی درگیر در معادن سطحی را ارزیابی می‌کند. برای این منظور، از یک فرآیند سلسله مراتبی تحلیلی برای تجزیه و تحلیل داده‌های تلفات و از TOPSIS فازی برای داده‌های آسیب‌ها استفاده می‌شود. می‌توان نتیجه گرفت که تمامی گروه‌های شغلی به دلیل خطرات مختلف در معرض خطرات تلفات جانی و جراحتی قرار دارند. با این حال، برخی از فعالیت‌ها بیشتر در معرض مرگ و میر هستند در حالی که برخی دیگر در معرض آسیب هستند. کارگران اغلب درگیر چنین حوادثی هستند. خطرات رایج مانند سقوط سنگ و لغزش از بالا بر همه گروه‌های شغلی یکسان تأثیر می‌گذارد. حوادث مربوط به لغزش از بالا منجر به تلفات بیشتر می‌شود، در حالی که خطرات مربوط به ماشین آلات منجر به صدمات بیشتر از تلفات می‌شود. خطرات ناشی از صدمات جزئی اغلب از نظر اقدامات پیشگیری و کنترل نادیده گرفته می‌شوند تا زمانی که منجر به صدمات / مرگ و میر جدی شوند. پیشنهاد می‌شود هر حادثه بدون در نظر گرفتن شدت، به طور منظم گزارش و تجزیه و تحلیل شود تا تکرار حوادث به حداقل برسد. اقدامات ضروری برای ایجاد یک محیط معدنی ایمن تر شامل اجرای مکانیزاسیون مناسب، ارائه آموزش منظم به کارگران، اعمال استفاده از تجهیزات حفاظت فردی و رعایت دقیق قوانین معدن است.

کلمات کلیدی: تلفات، جراحات، خطر، AHP، TOPSIS.