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MULTICRITERIA ANALYSIS OF OCCUPATIONAL HAZARDS IN UNDERGROUND MINING

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Abstract: Underground mining remains one of the most hazardous industries globally, exposing workers to a wide range of geo-mechanical, chemical, and ergonomic risks. This study systematically classifies occupational hazards—such as traumatic injuries, respiratory conditions, and musculoskeletal disorders—and evaluates evidence-based prevention strategies. The Analytic Hierarchy Process (AHP), a multi criteria decision-making (MCDM) method, is employed to assess and prioritize these hazards and the corresponding mitigation measures. The findings identify the most critical risks, including roof collapses, gas explosions, and dust exposure, and evaluate the effectiveness of various control strategies. The study offers practical insights for improving safety management in underground mining and underscores the importance of structured decision-making in hazard prevention.
Key words: occupational hazards, underground mining, AHP, safety management, prevention strategies.

INTRODUCTION

Underground mining remains one of the most hazardous industrial sectors due to the complex and dynamic nature of the working environment characterized by confined spaces, unstable geological conditions, exposure to harmful substances, and heavy machinery. Workers are exposed to multiple risks, including rock falls, gas explosions, poor ventilation, and ergonomic injuries. Globally, mining accounts for 1% of the workforce but 8% of fatal occupational injuries. Despite advancements in safety technologies and regulatory frameworks, mining accidents and occupational diseases continue to occur, leading to fatalities, long-term disabilities, and substantial economic losses [1-3]. To address these challenges, a systematic and multi criteria approach is essential for evaluating risks, prioritizing hazards, and implementing effective prevention strategies.

Traditional risk assessment methods often fail to capture the interdependencies between different hazards, necessitating a structured multi criteria approach.

The Analytic Hierarchy Process (AHP) is a robust MCDM technique that decomposes complex problems into hierarchical structures, allowing for pairwise comparisons of criteria and alternatives [4]. This paper applies AHP to:

- identify and prioritize key occupational hazards in underground mining,
- evaluate prevention strategies based on feasibility and effectiveness, and
- provide a decision-support framework for safety management in mining operations.

By analyzing various risk parameters, such as likelihood, severity, exposure frequency, and mitigation feasibility, this research aims to identify high-priority hazards and propose targeted prevention measures. The findings will contribute to enhancing safety protocols, and fostering a safer working environment for miners. Ultimately, this paper seeks to bridge the gap between theoretical risk assessments and practical safety interventions, providing actionable insights for mining companies, policymakers, and occupational health professionals.

For this reason, a multi-criteria analysis of the most important occupational hazards in underground mining was carried out in this paper, and general prevention measures in mining and in particular the prevention of injuries in underground mining were defined.

Many studies demonstrate effectiveness of AHP method in ranking safety interventions in mining [5].

MATERIAL AND METHODS

The original methodology is determined to achieve optimal results. The working methodology defined by the author is shown in Fig. 1.
Fig. 1 shows that the research begins with the process of identifying the groups of occupation hazards in underground mining. The methods were identified based on a literature review and on the data from underground mining companies in our country.

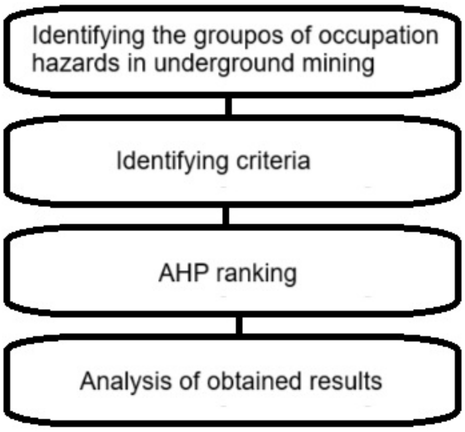

Fig. 1. *Schematic presentation of the work methodology*

In the next phase, the criteria were defined mainly on the basis of a literature review, but also on interview with mining experts and managers in our mines. The final list of groups of occupation hazards in underground mining and the criteria were finalised after these two phases.
Then the criteria were first ranked to identify the most influential criteria. The next step is to rank the groups of occupation hazards in underground mining. The AHP method was used for the ranking and the scores were given according to the group decision method (author with managers and experts from underground mines in the mines of our country).
Once the ranking list was drawn up, the results were analysed with the aim of identifying the most dangerous groups of occupational hazards in underground mining and determining general prevention measures in mining and, in particular, for the prevention of injuries in underground mining.

AHP METHOD

The Analytic Hierarchy Process (AHP) is a structured decision-making method. It helps to analyses complex decisions by breaking them down into a hierarchy of criteria and alternatives and then determining priorities through pairwise comparisons. The main theoretical principles of AHP include hierarchy building (decomposing the problem into a hierarchy of objectives, criteria, sub-criteria and alternatives), pairwise comparisons (comparing the elements at each level using a scale of 1-9 – Tab. 1.), calculation of priority vectors (using the eigenvector method to derive weights from the comparison matrix to ensure consistency), consistency checking (calculating the consistency ratio (CR) to ensure that the judgements are logically coherent (CR < 0.1 is acceptable)) and aggregation of weights (combining local priorities across the hierarchy to obtain global weights for alternatives).
AHP has many advantages, such as considering both qualitative and quantitative criteria and providing a systematic and transparent decision framework.
The main limitations are: Subjectivity in pairwise comparisons, can become complex with many criteria/alternatives.
AHP is used today in business, engineering, healthcare and politics for multi-criteria decision analysis.

Table 1. *AHP comparison scale*

Dominance	
Description	**Mark**
Equal	1
Weak dominance	3
Strong dominance	5
Very strong dominance	7
Absolute dominance	9
2, 4, 6, 8 are intermediate values	

RESULTS AND DISCUSSION

Identifying the groups of occupation hazards in underground mining

As previously noted, the categories of occupational hazards in underground mining were identified through a comprehensive literature review and consultations with mining experts in our country.
The most prevalent occupational hazards in underground mining, along with their descriptions, potential consequences, and recommended preventive measures, are outlined below:

- *Injuries caused by falling earth, stones and falling objects (Alternative A1)* – this hazard category includes impacts from fractured rocks, dropped tools, equipment, or loads during lifting operations. It accounts for approximately 34% of fatalities in underground mining. *Description*: collapse of pit walls, ceilings, or falling material from elevated areas. *Potential consequences*: severe physical trauma, bone fractures, and fatal injuries. *Preventive measures*: regular assessment of ground and structural stability, installation of appropriate support systems (e.g., rock bolts, mesh, piles), and strict adherence to safety protocols during excavation activities.
- *Injuries caused by handling heavy machinery (Alternative A2)* – this category encompasses injuries resulting from entrapment in moving machine parts (e.g., drills, conveyor belts), incidents involving tools or rock fragments during drilling, blasting, or transport, collisions with mining vehicles (e.g., locomotives, haul trucks), and accidents during loading or unloading operations. Conveyor belts and drilling equipment alone are responsible for approximately 22% of non-fatal injuries in underground mining. *Description*: injuries sustained during the operation of or proximity to heavy mining machinery, including excavators, drills, and conveyor systems. Potential consequences: amputations, contusions, bone fractures, and other serious injuries. *Preventive measures*: comprehensive worker training on equipment operation, routine maintenance of machinery, and consistent use of personal protective equipment (PPE).
- *Inhalation of harmful gases and dust (Alternative A3)* – this hazard includes exposure to respiratory dust (e.g., silica) and toxic gases (e.g., methane, carbon monoxide), leading to occupational diseases such as pneumoconiosis ("black lung"), silicosis, and other chronic respiratory conditions. Additional risks include noise-induced hearing loss and dermal or ocular damage from chemical agents. *Description*: prolonged or repeated exposure to airborne contaminants in confined underground environments. *Potential consequences*: chronic lung diseases (e.g., silicosis, pneumoconiosis), systemic poisoning, hearing loss, and chemical burns to the skin and eyes. *Preventive measures*: implementation of effective ventilation systems, continuous gas monitoring, use of respirators and filter-equipped masks, and application of wet drilling techniques, which can reduce airborne dust by up to 90%.
- *Explosions and burns (Alternative A4)* – this hazard involves burns and other injuries resulting from the detonation of explosives or accidental fires. Explosions may occur due to the accumulation of flammable gases such as methane or the improper handling of explosive materials. *Description*: high-energy incidents caused by gas build-up (e.g.,

methane) or misuse of explosives in confined underground environments. *Potential consequences*: thermal burns, traumatic injuries, and fatalities. *Preventive measures*: rigorous monitoring and control of methane concentrations, comprehensive training in explosive handling, and the use of antistatic equipment and spark-suppression systems.

- *Falls, slips and trips (Alternative A5)* – this category includes accidents caused by falling from heights (e.g., platforms, stairs, or unstable surfaces), slipping on wet or uneven terrain, or tripping over tools, cables, or mining equipment. *Description*: incidents typically occur during movement across wet, muddy, inclined, or obstructed surfaces within the underground work environment. *Potential consequences*: sprains, bone fractures, concussions, and other musculoskeletal injuries. *Preventive measures*: regular cleaning and maintenance of walkways, secure placement of equipment and materials, use of slip-resistant footwear, and clear marking of hazardous zones.
- *Injuries due to manual handling of loads, overexertion and poor working posture (Alternative A6)* – this hazard encompasses musculoskeletal disorders resulting from lifting, carrying, or moving heavy or awkwardly shaped loads without proper technique, as well as sustained poor posture during work activities. *Description*: physical strain caused by manual handling tasks performed without ergonomic consideration or mechanical assistance. *Potential consequences*: injuries to the spine, muscles, and joints, including chronic back pain and repetitive strain injuries. *Preventive measures*: training in proper lifting techniques, use of mechanical aids such as trolleys and cranes, and mechanization of manual tasks wherever feasible.

Identifying the criteria

The identification of criteria was based on a comprehensive literature review and interviews with mining experts and site managers from domestic mining operations. Four key criteria were identified as the most critical, namely:

- *Severity (Criteria C1)*: This criteria denotes the extent of harm or adverse impact that a hazard may inflict upon a worker's health or safety should an incident occur. It assesses the potential consequences, ranging from minor injuries to life-threatening conditions.
- *Frequency (Criteria C2)*: This criteria reflects the regularity with which workers are exposed to hazardous conditions, accidents, or occupational health risks in underground mining operations. It encompasses both acute incidents (e.g., roof collapses, explosions) and chronic health risks (e.g., respiratory diseases due to prolonged dust exposure).
- *Controllability (Criteria C3)*: This parameter evaluates the degree to which mining operators and workers can prevent, mitigate, or manage occupational hazards through engineered controls, administrative measures, safety protocols, and the use of personal protective equipment (PPE).
- *Economic impact (Criteria C4)*: This criteria refers to the direct and indirect financial repercussions of workplace accidents, injuries, illnesses, and fatalities on mining operations, stakeholders, and society at large. These impacts may manifest as immediate costs (e.g., emergency response and compensation) or long-term effects (e.g., diminished productivity due to chronic occupational diseases).

AHP ranking

Once all alternatives and criteria have been identified, the Analytic Hierarchy Process (AHP) method is applied. The ranking was conducted using the online AHP tool available on GitHub Pages (https://comcastsamples.github.io/ahp-tool). As previously stated, the objective is to rank occupational hazards in underground mining to support injury prevention efforts.
The ranking of the measures was carried out by managers and mining experts, as noted earlier. First, a pairwise comparison matrix for the criteria (Tab. 2) was established to determine

their relative influence on the final ranking of alternatives—occupational hazards in underground mining.

Table 2. *Comparison marks of criteria*

	C1	**C2**	**C3**	**C4**
C1	1	3	1/2	1
C2		1	1/5	1/5
C3			1	1/2
C4				1

Following the calculations, the weighting coefficients for the criteria were derived based on the pairwise comparison scores presented in Tab. 2 (results illustrated in Figure 2).

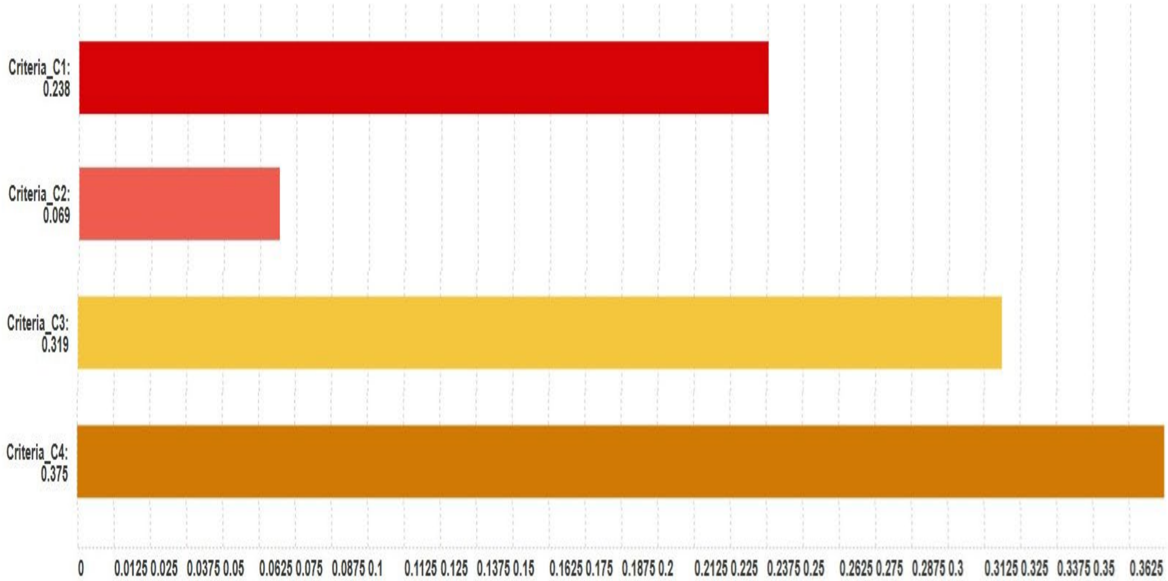

Fig. 2. *The obtained weighting coefficients of the criteria*

Subsequently, the mining method groups (alternatives) were evaluated against each of the four predefined criteria, as detailed in Tables 3–6.

Table 3. *Comparison of the alternatives with respect to criteria C1*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**
A1	1	1	3	1/3	4	6
A2		1	3	1/3	4	6
A3			1	1/6	2	3
A4				1	6	7
A5					1	1
A6						1

Table 4. *Comparison of the alternatives with respect to criteria C2*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**
A1	1	1/2	1/5	1	1/3	1/5
A2		1	1/3	2	2	1
A3			1	3	2	1
A4				1	1/3	1/5
A5					1	1/2
A6						1

Table 5. *Comparison of the alternatives with respect to criteria C3*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**
A1	1	2	1	1/3	2	1
A2		1	1/3	2	1	1/2
A3			1	3	2	3
A4				1	1/3	1/4
A5					1	1
A6						1

Table 6. *Comparison of the alternatives with respect to criteria C4*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**
A1	1	4	5	1/2	5	5
A2		1	2	1/6	2	4
A3			1	1/6	1	2
A4				1	5	7
A5					1	2
A6						1

Finally, the ranking results for the alternatives were determined, as presented in Fig. 3.

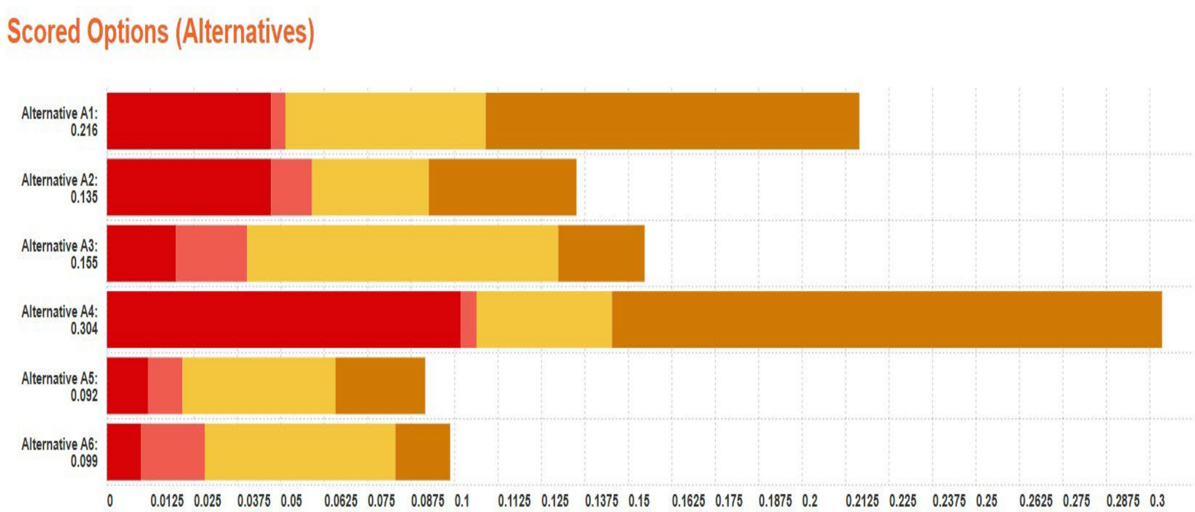

Fig. 3. *The obtained final rank of the alternatives*

Analysis of obtained results

The analysis incorporates both the evaluation criteria and their respective impacts on the ranking outcomes, along with the alternatives (occupational hazards in underground mining). Regarding the criteria analysis, particular attention is given to their weighting coefficients, which quantitatively represent each criteria's relative influence on the final ranking of alternatives.
From Fig. 2., it is evident that criteria C4 (economic impact) exerts the greatest influence on the ranking results, with a weighting coefficient of 0.375. This indicates that direct and indirect financial consequences have the most significant effect on mining companies in terms of occupational hazards. Such economic losses impact all stakeholders within mining operations, from individual workers to the organization as a whole.
Criteria C3 (controllability) ranks second. This factor reflects the capacity to manage and mitigate occupational hazards, highlighting the potential to reduce or even eliminate many adverse incidents.

Criteria C1 (severity) occupies the third position. This is a critical factor, as severe injuries, occupational diseases, and fatalities occur at a considerably higher rate in underground mining compared to other industries.

Finally, criteria C2 (frequency) ranks last. Despite its position, it remains a key parameter, as it reflects how often occupational hazards materialize. The frequency of such hazards serves as an essential indicator in identifying the most severe risks.

Regarding the occupational hazards (alternatives) presented in Fig. 3, the most severe is A4 (explosions and burns). This hazard is characterized by a high number of worker injuries and fatalities, miners being trapped underground, and significant economic and material losses. In some cases, such incidents have led to permanent mine closures—for example, the Aleksinac coal mine in Serbia.

Ranking second is alternative A1 (injuries caused by falling earth, rocks, and collapsing structures). These hazards also pose serious risks, frequently resulting in severe injuries, fatalities, and substantial material damage. Moreover, they often cause prolonged or even indefinite operational disruptions in affected sections of underground mines.

Alternative A3 (inhalation of harmful gases and dust) occupies third place. These hazards contribute to chronic occupational diseases, long-term disability, and, in extreme cases, fatalities among severely affected workers.

In fourth place is alternative A2 (injuries caused by handling heavy machinery). Modern underground mining relies heavily on mechanized equipment, which, while improving efficiency, also increases the risk of severe and sometimes fatal worker injuries. Additionally, prolonged exposure to machinery-related hazards—such as noise and vibration—can lead to occupational illnesses.

Alternative A6 (injuries due to manual handling of loads, overexertion and poor working posture) ranks fifth. Despite advances in mechanization, mining remains labor-intensive compared to other industries. Cramped workspaces, high temperatures, poor ventilation, and the physical demands of manual loading and unloading contribute to musculoskeletal injuries and long-term disabilities.

Finally, alternative A5 (falls, slips, and trips) is ranked last. Uneven terrain, water accumulation, mud, and confined spaces create hazardous conditions that frequently lead to worker injuries from falls and slips.

Occupational safety management in underground mining encompasses two key categories of interventions: general safety measures and injury prevention strategies.

General Safety Measures – these measures establish a foundational safety framework and include:

- Training and education: Regular and comprehensive instruction on occupational health and safety protocols to ensure worker competency.
- Personal protective equipment (PPE): Mandatory use of helmets, safety goggles, gloves, reinforced footwear, high-visibility clothing, and respirators to mitigate exposure to hazards.
- Inspection and maintenance: Systematic technical evaluations of mining equipment and infrastructure to ensure operational integrity.
- Emergency preparedness: Clearly defined evacuation plans, marked escape routes, and readily available fire suppression systems.
- Health surveillance: Periodic medical examinations and continuous monitoring of workers' health to detect occupational illnesses early.
- Safety culture promotion: Encouraging transparent reporting of unsafe conditions and near-miss incidents to foster proactive hazard mitigation.

Injury Prevention Strategies – these targeted interventions aim to reduce workplace accidents and include:

- Continuous safety training: Reinforcement of hazard awareness and safe work practices.
- Strict PPE compliance: Enforcement of protective gear usage (e.g., helmets, respirators, impact-resistant footwear).

- Machinery upkeep: Preventive maintenance and timely repairs of mining equipment to minimize mechanical failures.
- Geotechnical monitoring: Regular assessment of rock stability combined with adequate roof and wall support systems.
- Atmospheric control: Real-time gas detection and effective ventilation to prevent toxic exposure and explosions.

Given that mining remains one of the world's most dangerous professions, the rigorous implementation of these measures is critical to reducing occupational risks and safeguarding worker well-being.

CONCLUSION

In this article, the Analytic Hierarchy Process (AHP) method was applied to rank occupational hazards in underground mining. The analysis considered the most prevalent hazards in this sector, together with their definitions, potential consequences, and recommended preventive measures. The hazards evaluated included: injuries caused by falling earth, stones, and other objects (Alternative A1); injuries resulting from the operation of heavy machinery (Alternative A2); inhalation of harmful gases and dust (Alternative A3); explosions and burns (Alternative A4); falls, slips, and trips (Alternative A5); and injuries arising from manual handling of loads, overexertion, and poor working posture (Alternative A6).

The ranking was conducted according to four criteria: severity (Criteria C1), frequency (Criteria C2), controllability (Criteria C3), and economic impact (Criteria C4). The AHP results identified explosions and burns (Alternative A4) as the most hazardous occupational risk. Among the criteria, economic impact (Criteria C4) exerted the greatest influence on the overall ranking of hazards.

The study further outlines key preventive measures in occupational safety management, emphasizing both general safety protocols and specific strategies for injury prevention.

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REFERENCES

[1] Baghaei Naeini, S. A., Badri, A., Identification and categorization of hazards in the mining industry: A systematic review of the literature. International Review of Applied Sciences and Engineering, Vol. 15, No. 1, pp. 1-19, 2024.
[2] Cliff, D., OHS in the Mining Industry in the 21st Century. University of Wollongong. Conference contribution, 2016.
[3] Elenge, M.M., De Brouwer, C., Identification of hazards in the workplaces of Artisanal mining in Katanga. IJOMEH, Vol.24, pp. 57–66, 2011.
[4] Saaty, T.L.: The Analytical Hierarchy Process, McGraw-Hill, New York, 1980.
[5] Nieto-Morote, A., Ruz-Vila, F., A fuzzy approach to construction project risk assessment. International Journal of Project Management, Vol. 19, No 2, pp. 220-231, 2011.