Concrete Projection in Mines - Associated Risks

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Abstract

This article analyzes the risks associated with the application of shotcrete in underground mining galleries, from the point of view of occupational health and safety. In this way, with the awareness of the risks in this activity and in this environment, it is possible to improve and even optimize the behavior of workers to avoid possible accidents during its application. We can prioritize problems based on the GUT Matrix. It is possible to identify which of them require an immediate response and which can be dealt with later. To this end, a cross-sectional study was carried out using direct observation. The data collected were entered into the IBM SPSS 28.0.1.0 (IBM Corp., Chicago, IL, USA) software and subsequently a descriptive analysis was carried out to respond to the objectives of the study and obtain correlations between the verified factors. To achieve the objectives, bibliographical research was carried out on the topic and international regulations served as the basis for the study. After identifying the dangers and possible causes of accidents or risks, the factors that make up the simplified Risk Assessment methodology were quantified. This activity carries health risks, such as lung disease due to inhalation of silica contained in the cement. Therefore, the use of protective equipment, such as a hood with a supply of clean external air or masks that completely filter the smallest particles, as well as worker's rotation are of great importance. This work is original because there is not much literature about the use of this technique in works in underground galleries, with the thermal issue of the environment as the biggest limitation, in contrast to open-air works, where the use of this technique is more common.

Keywords: *Shotcrete, underground mine, risks, occupational health and safety, Portugal*

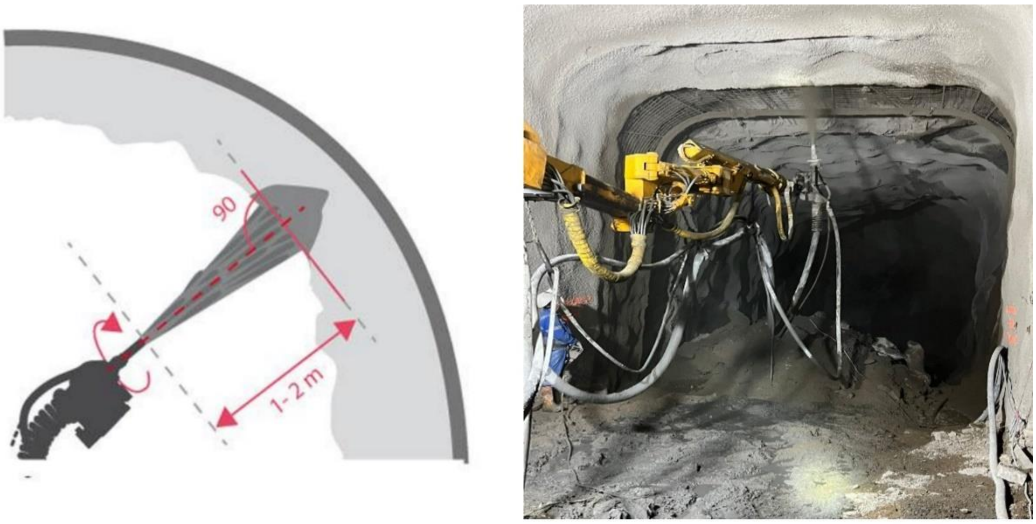
1. Introduction

The underground mine selected as a case study is located in Aljustrel, Portugal, and served as a laboratory for the professional workers involved in the research.

The extractive industry is one of the main economic activities of Portugal, contributing 2.3% of the national GDP, which represents an important boost for economic development. The production of geological and industrial natural resources has the potential to generate significant economic value [1]. However, it is one of the industrial sectors with the highest incidence of accidents, including falls, crushes, shocks and other incidents that result in injuries or even death of workers. In 2021, there were 750 registered occupational accidents in the extractive industry sector in Portugal, while in the European Union, the total was, in 2020, 497 196 [2].

The application of shotcrete (projected concrete) is a common practice in underground mining operations, needs much caution and diligence and is used to strengthen and stabilize the structures of galleries and tunnels. This technique offers significant advantages in terms of application speed, efficiency and durability. However, its application in underground environments presents a number of peculiar challenges, including adverse working conditions, safety risks and proper selection of equipment and materials.

Figure 1(a) shows the appropriate position of the projection tip, positioned at 45º degrees from the surface to be projected. In this way, a distance is ensured between the tip of projection and the surface to be projected that is within the acceptable tolerance range, varying from 1 to 2 meters. This configuration is combined with tip movement speeds to ensure effective projection. Figure 1(b) shows a projection on the ceiling of a gallery, where the tip is positioned to ensure proper compaction on the ceiling. This is achieved by positioning the tip perpendicularly relative to the ceiling surface or to the surface to be designed.



(a) (b)

Fig. 1. Illustration of the appropriate way to apply the shotcrete. (a) Proper position of the projection tip and the distance limits. (b) position of the tip perpendicular to the surface (authors)

These concerns led to the creation of Portuguese agencies with authority to establish specific regulations, such as the Direção-Geral de Energia e Geologia [General Directorate for Energy and Geology] and the Agência Portuguesa do Ambiente [Portuguese Environment Agency], which establish national and specific standards for each activity, based on European standards and procedures.

Usually, workers in the mining industry often face various occupational hazards while in the mines, especially when they do not have access to adequate protective equipment such as masks, gloves and visors. In these circumstances, they often work without clear guidelines, and suffer pressures to quickly carry out their tasks [3]. Additionally, there are several associated risks, such as inhalation of dust, smoke and gases, detachment and fall of rock blocks, poisoning by chemicals, exposure to noise and vibration, musculoskeletal injuries, projection of work equipment components, application of concrete under high pressure and falls from different levels.

In this scenario, workers face several physical challenges due to the rigorous work environment, the lack of adequate protection measures and long working hours, often associated with unhealthy lifestyles. In addition, they are exposed over time to harmful chemicals products present in building materials and suspended solid particles in the air [4], including cement silica.

The main objective of this study was to analyze the risks associated with the use of shotcrete in underground mining galleries, in addition to addressing safety practices related to associated events. It was also aimed to suggest measures to mitigate these risks in order to improve working conditions. Finally, a descriptive analysis was carried out.

The present study had as methodology, a bibliographic survey, which was used as a source of research, and direct observation of the professionals who exercise the activity of the application of shotcrete in galleries. In this sense, an observational, direct approach and a cross-sectional study were carried out for a better perception of the associated risks during the activity. The collected data were introduced in a software in order to explore the correlation between the research results. Finally, risk assessment was introduced through a GUT (Gravidade, Urgência e Tendência [Severity, Urgency and Tendency]) Matrix.

2. Material and Methods

In the underground mine selected for the study and previously mentioned, the research area covers eight underground galleries located in a depth between 540 and 560 meters, with dimensions ranging from W - 5.0 m, H - 5.0 m, W - 5.0 m H - 5.5 m and W - 6.0 m, H - 7.0 m, where W represents the width and H the height of the galleries.

To organize the work teams, a system of rotating work in shifts was adopted, considering the risks inherent in working conditions. Through direct observation, the main risks associated with the application of the shotcrete were identified. Based on these findings, it was possible to present some conclusions and suggestions to mitigate the risk problems present in the sector.

In this study, the GUT Matrix is used to analyze the risks associated with the application of shotcrete in underground mines, in order to quantify and classify the priority of the risk associated with the activity. The GUT Matrix classifies risks based on three criteria: Severity (G), Urgency (U) and Tendency (T). Severity refers to the Severity of the impact if the risk materializes, Urgency refers to how quickly the risk needs to be addressed and Tendency refers to the likelihood of the risk occurring in the future (Table 1). The criteria may include qualitative and quantitative aspects, but in this work, it was chosen to use only qualitative criteria, as they allow to evaluate the subjective aspects of the situation, taking into account factors such as human impact.

Tab. 1. GUT risk matrix classification for the mining sector (adapted from [5])

GUT Matrix	Risk classification
Severity (G)	Classified according to the impact on people and its consequences.
Urgency (U)	Analyzed based on the period in which the worker is exposed to risk during his working day.
Tendency (T)	Performs the assessment of the Severity of damage, injury or danger to people.

Risks are scored on a scale of 1 to 5 for each criterion, where 1 means low priority and 5 means high priority and the total score determines the priority of risk [6]. The calculation of risk prioritization is performed by multiplying the score obtained for each criterion of the GUT Matrix (eqn. 1). According to the adopted model, the higher the result, the higher the priority assigned.

$$G \times U \times T = risk\ priorization \qquad (1)$$

This tool allows to identify priority problems considering their Severity, Urgency and Tendency. By using the GUT matrix, we can assist the organizational environment by answering questions such as: What is a priority? Where to start? among others [6].

The results presented in this paper are qualitative and were achieved based on the methodology described above. From Table 2 it is feasible to classify and sort the priorities according to an approach closer to reality.

Tab. 2. Score assigned to the GUT matrix (adapted from [5])

Points	Severity	Urgency	Tendency
1	No gravity	No hurry	It won't get worse or it might get better
2	Minor Severity	Can wait a while	Will get worse in the long term
3	Serious	As soon as possible	Will get worse in the medium term
4	Very serious	With some Urgency	Will get worse in the short term
5	Extremely serious	An immediate action is required	If nothing is done, the aggravation will be immediate

To elaborate the GUT Matrix, the main risks involved in the application of shotcrete in the underground galleries were examined and evaluated. These risks were categorized into five types: physical, chemical, biological, ergonomic and accidental, in the following way:

1. Noise (physical risk): Excessive noise of the projection robot during application, without proper protections, can result in permanent and irreversible hearing damage, thus causing physical damage.
2. High humidity (physical risk): Activities performed in humid places can result in dermatological problems and loss of body heat, generating a physical risk. Moisture is common in flooded or soaked environments, and in confined places such as underground mines.
3. Thermal overload (physical risk): When a worker is exposed to elevated temperatures, his work efficiency decreases significantly. The speed of execution of tasks reduces, pauses become more frequent, the probability of accidents increases and the ability to concentrate decreases.
4. Inhalation of dust, smoke and gases (chemical risk): When working in confined spaces, the main danger arises from exposure to gases, vapors and dust present during the activity. The process itself generates a significant amount of dust and silica from the cement, posing a chemical risk to health and can result in inhalation and intoxication.
5. Presence of microorganisms (biological risk): The decomposition of organic matter is the cause of this situation. Many diseases result from exposure to microorganisms such as bacteria, viruses and protozoa when basic protective precautions are not followed. Environments with high humidity, and confined as underground, provide ideal conditions for the proliferation of these microorganisms, causing a biological risk.
6. Inadequate posture (ergonomic risk): Causes a number of health complications such as muscle and head pain, concentrating difficulty and even digestive problems. This results in both physical and psychological wear for the worker thus generating an ergonomic risk.
7. Musculoskeletal lesions (ergonomic risk): These are lesions that result from repetitive movements or inappropriate postures during work activities. They may include tendinitis, bursitis and carpal tunnel syndrome.
8. Detachment and rock falls (accidental risk): During the application of shotcrete, there is a potential risk of rock blocks being detached from the ceiling, as well as fragments of aggregates, putting the worker in danger of being hit and suffering physical damage.
9. Falls from different levels (accidental risk): These incidents occur in areas devoid of signaling and collective protection measures, leaving openings exposed and prone to causing accidents of various degrees of Severity at different levels.
10. Falls at the same level (accidental risk): Tripping on rocks occurs when the track is not properly cleaned and in good working condition, resulting in uneven floors. This can lead to accidents and injuries.
11. Trampling (accidental risk): The operation of the projection robot is restricted to licensed operators, specialized training and authorization to operate it, being the trampling and crushing, two of the main risks of accidents involving the equipment.
12. Fresh concrete drop (accidental risk): It represents a physical risk or, more specifically, a risk of falling objects. This type of risk occurs when fresh concrete, still in liquid or semi-liquid state, falls from a high height, and can reach workers on site.
13. Bursting/projection of work equipment components (accidental risk): Represents a risk of serious accidents in work environments where this activity is performed. This type of risk is associated with the operation of concrete projection equipment such as concrete pumps, projection hoses and spray nozzles.

The results obtained after the evaluation of the criteria together are presented below. From these results, a general value can be determined in the GUT matrix that represents the relative priority of the problem in relation to other problems or situations. This process is important to guide decision making on resource allocation and problem solving more effectively and timely.

3. Results

Table 3 presents the results of the GUT Matrix elaborated for this case study, including its classification and the ordering of risks related to the application of projected concrete in underground mine galleries, based on priorities.

The relationship between the GUT Matrix and the priorities lies in the fact that the problems or situations that have the highest score in the matrix (i.e., greater Severity, Urgency and Tendency) are considered more critical and, therefore, their approach and resolution have a high priority.

Tab. 3. GUT Matrix classification (adapted from [5])

GUT MATRIX	G	U	T	TOTAL	PRIORITY
PHYSICAL RISKS					
Noise	**3**	**4**	**2**	**24**	**4th**
High humidity	**3**	**4**	**2**	**24**	**4th**
Thermal overload	**4**	**4**	**2**	**32**	**2nd**
CHEMICAL RISKS					
Inhalation of dust, smoke and gases	**5**	**5**	**2**	**50**	**1st**
BIOLOGICAL RISKS					
Presence of microorganisms	**3**	**2**	**2**	**12**	**5th**
ERGONOMIC RISKS					
Inadequate posture (long time looking at the ceiling)	**3**	**3**	**3**	**27**	**3rd**
Musculoskeletal lesions	**4**	**5**	**2**	**40**	**2nd**
ACCIDENTAL RISKS					
Detachment and rock falls	**4**	**4**	**4**	**64**	**1st**
Falls from different levels	**3**	**3**	**2**	**18**	**5th**
Falls at the same level	**3**	**3**	**2**	**18**	**5th**
Trampling	**3**	**2**	**2**	**12**	**5th**
Fresh concrete drop	**5**	**5**	**3**	**75**	**1st**
Bursting/projection of work equipment components	**4**	**4**	**2**	**32**	**2nd**

Moreover, in underground environments, it is feasible to identify environmental and accident hazards through case studies. In this way, in the underground mine of Aljustrel, risks related to the application of shotcrete in galleries were identified, so the following presents the five main risks associated with the application of the projected concrete and its prioritization.

1. Physical risks - 4th and 2nd. Due to the thermal conditions underground, even with ventilation, a thermal imbalance occurs in the body due to the confined work environment. This results in higher heat absorption than dissipation, causing physiological effects. On the other hand, noise can be managed with the proper use of Personal Protective Equipment (PPE) such as earplugs. However, improper use or lack of such equipment can result in hearing loss, often irreversible.
2. Chemical risks - 1st. This risk, classified as a priority, refers to the inhalation of dust, smoke and gases, especially during the application of shotcrete, which contains additives and silica. This exposure can result in serious health problems for the worker, such as silicosis, which occurs when these substances are retained in the lung tissues.
3. Biological risks - 5th. Although classified as a fifth priority in underground environments, this risk has to be taken into account. Microorganisms can affect workers' quality of life, especially when related to contaminated food and water, as well as inhalation of droplets from sneezing or coughing.
4. Ergonomic risks - 3rd and 2nd. In underground locations, where physical exertion may be necessary for long periods and in a fixed position, this type of danger can result in physical and psychological wear, inadequate postures and musculoskeletal injuries.
5. Accidental risks - priority 1st, 2nd and 5th. This danger is present in all activities, especially in the initial one, where detachment, rock falls and fresh concrete drop can occur. These incidents occur when the production cycle does not run properly. Before starting the projection, it is essential to perform mechanical cleaning in the gallery section, thus minimizing these risks.

The graph in Figure 2 shows the ranking of the risks by their GUT score and, consequently, by priority, highlighting the importance of each risk. Priorities are determined by the product of the values assigned to the Severity, Urgency and Tendency of each risk, according to eqn. 1, as indicated above. Subsequent priorities are ordered according to their respective scores, allowing for a strategic and focused approach to solutions of the challenges identified.

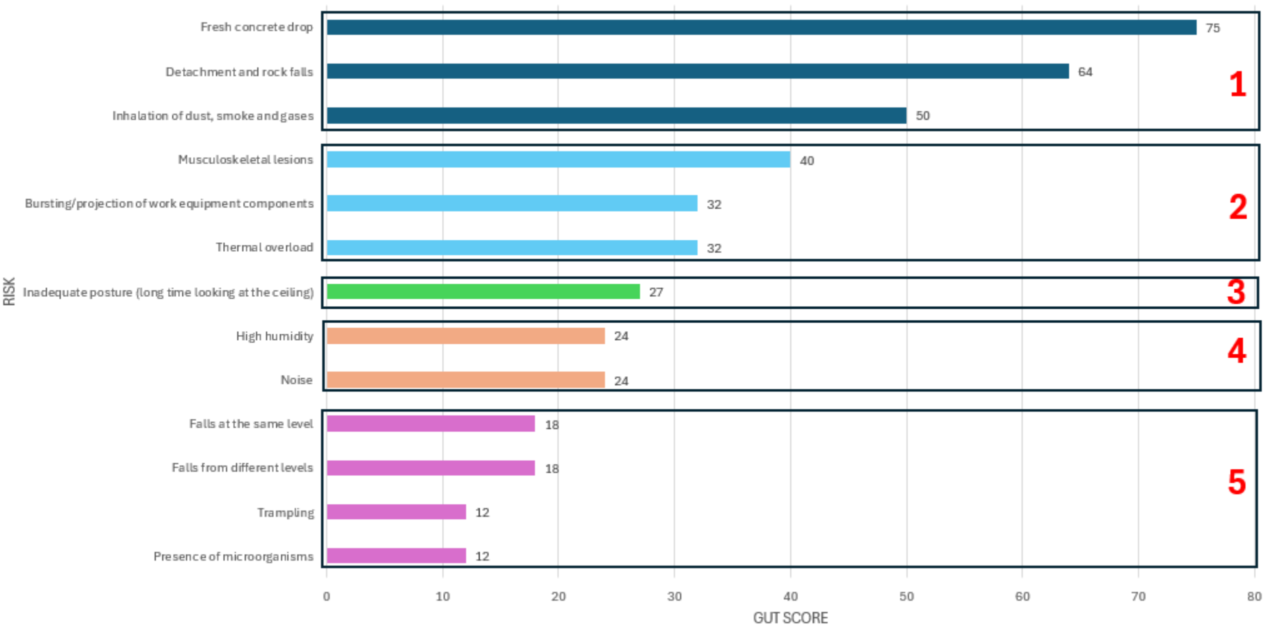


Fig. 2. Risk priority according to GUT scores (authors)

As presented above, 13 risks were considered in this study, 3 (23.1 per cent) of them were considered physical risks, 1 (7.7 per cent) chemical, 1 (7.7 per cent) biological, 2 (15.4 per cent) ergonomic and 6 (46.2 per cent) accidental risks (Figure 3).

Risk Type

	N	%
Physical Risk	3	23,1
Chemical Risk	1	7,7
Biological Risk	1	7,7
Ergonomic Risk	2	15,4
Accidental Risk	6	46,2
Total	13	100,0

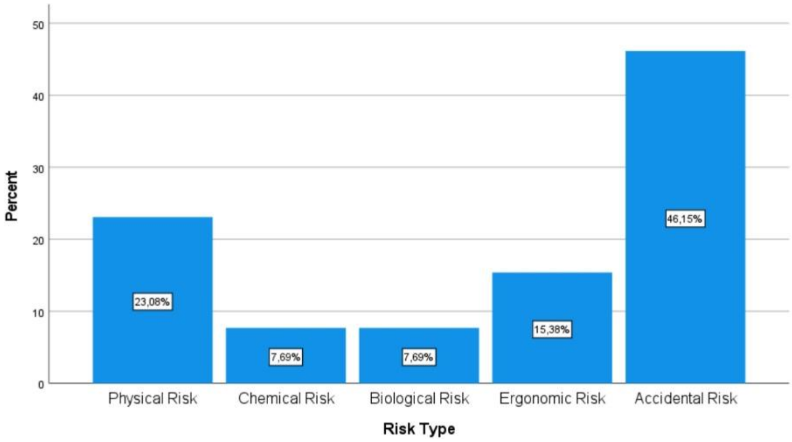


Fig. 3. Risk Type by Frequency (authors)

The risks were analyzed according to the Severity, Urgency and Tendency criteria, and according to the score obtained in the GUT Matrix. With regard to the Severity criterion, there was a minimum score of 3 and a maximum of 5. In addition, 7 (53.8%) of the risks were classified with Severity level 3, 4 (30.8%) with level 4 and 2 (15.4%) with level 5. It can be concluded that the risks have high levels of Severity, with a mode of 3, with no risks classified as level 1 or 2 (Figure 4).

Severity

	N	%
3	7	53,8
4	4	30,8
5	2	15,4
Total	13	100,0

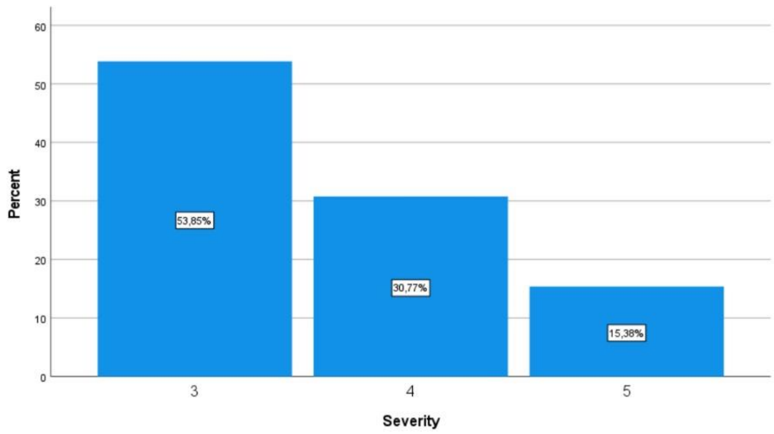


Fig. 4. Risk Type by Severity (authors)

With regard to the Urgency criterion, there was a minimum score of 3 and a maximum of 5. Furthermore, 2 (15.4%) of the risks were classified as level 2, 3 (23.1%) as level 3, 5 (38.5%) as level 4 and 3 (23.1%) as level 5. It can be concluded that the risks have high levels of Urgency, with mode 4, and there are no risks classified as level 1 (Figure 5).

Urgency

	N	%
2	2	15,4%
3	3	23,1%
4	5	38,5%
5	3	23,1%

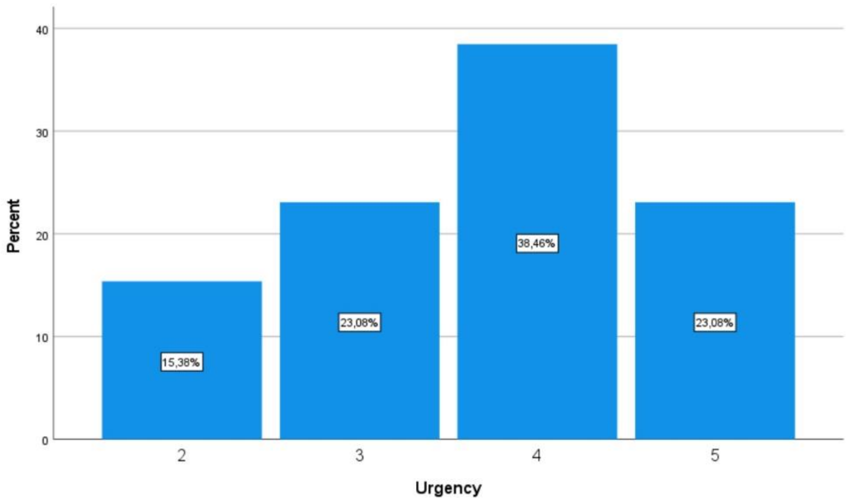


Fig. 5. Risk Type by Urgency (authors)

When the risks were analysed in terms of Tendency, there was a minimum score of 2 and a maximum of 4 and 10 (76.9%) of the risks have been classified as level 2, 2 (15.4%) as level 3 and 1 (7.7%) as level 4. In this case, it can be concluded that the risks have low Tendency levels, with a mode of 2, and there are no risks classified as level 1 or level 5. The distribution of Tendency values is in the opposite direction to the other two criteria (Figure 6).

Tendency

	N	%
2	10	76,9%
3	2	15,4%
4	1	7,7%

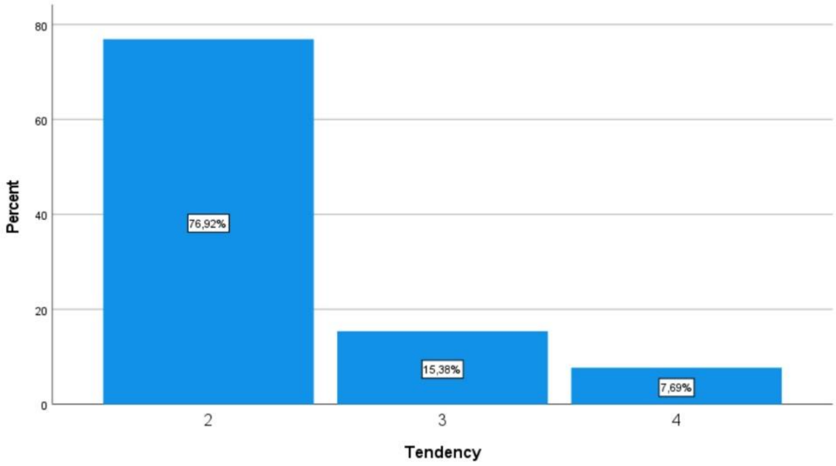


Fig. 6. Risk Type by Tendency (authors)

To analyse the correlation between the GUT scores and the scores of each of the used criteria, the correlation matrix was determined using Spearman's correlation coefficient. As noted above, the Tendency values behave in the opposite way to the values of the other two criteria, so analysing the correlation between the obtained GUT scores shows that there is a significant strong positive correlation with the Severity values ($r=0.890$; $p<0.001$) and with the Urgency values ($r=0.890$; $p<0.001$), but not with the Tendency values ($r=0.551$; $p=0.051$) (Table 4). There is also a positive correlation between the Severity and Urgency values ($r=0.818$; $p<0.001$), but not between the Severity and Trend values ($r=0.278$; $p=0.357$), nor between the Urgency and Trend values ($r=0.151$; $p=0.621$).

Tab. 4. GUT Scores, Severity, Urgency and Tendency Correlations (authors)

Correlations

			GUT	Severity	Urgency
Spearman's rho	Severity	Correlation Coefficient	,890**		
		Sig. (2-tailed)	<,001		
		N	13		
	Urgency	Correlation Coefficient	,873**	,818**	
		Sig. (2-tailed)	<,001	<,001	
		N	13	13	
	Tendency	Correlation Coefficient	,551	,278	,151
		Sig. (2-tailed)	,051	,357	,621
		N	13	13	13

**. Correlation is significant at the 0.01 level (2-tailed).

4. Discussion

The results of the analysis using the GUT Matrix revealed that the main risks associated with the application of shotcrete in underground mines include rockfalls, exposure to chemical products, collapse of structures and accidents at work. These risks were classified on the basis of their Severity, Urgency and Tendency, allowing areas of greatest concern to be identified and mitigation measures to be prioritized.

In this case study, 13 risks were analyzed, of which 3 (23.1%) are considered physical risks, 1 (7.7%) chemical, 1 (7.7%) biological, 2 (15.4%) ergonomic and 6 (46.2%) accidental risks. With regard to the criteria of the GUT Matrix, in relation to the Severity criterion, it was found that the risks have high levels of Severity, with a mode of 3, with no risks classified as level 1 or 2. With regard to the Urgency criterion, the risks were found to have high levels of Urgency, with a mode of 4, and there were no risks classified as level 1. However, in terms of the Tendency criterion, the risks were found to have low Tendency levels, with a mode of 2, with no risks classified as level 1 or level 5. The distribution of Tendency values was in the opposite direction to the other two criteria. The analysis of the correlation between the GUT scores and the scores of each of the criteria used confirmed that the behavior of the Tendency values was opposite to the distribution of the values of the other two criteria, since it was found that there is a significative strong positive correlation between the obtained GUT scores and the Severity values and the Urgency values, but not with the Tendency values. In this sense, it can be concluded that the Severity and Urgency values strongly influence the GUT scores and that the Tendency values do not. In other words, it can be concluded that, on the one hand, the greater the Severity of the risk and the greater the Urgency of intervention, therefore the greater the prioritization. On the other hand, the lower the risk Severity and the lower the Urgency of intervention, therefore the lower the prioritization.

There is also a positive correlation between the Severity and Urgency values, but there is no correlation between the Severity and Tendency values, nor between the Urgency and Tendency values. It can therefore be concluded, on the one hand, that the greater the Severity of the risk, the greater the Urgency of intervention, but not necessarily a worsening of the situation. On the other hand, the lower the risk Severity, the lower the Urgency of intervention, but not necessarily an alleviation of the situation.

Based on the results of the risk analysis, it is possible to propose various mitigation measures and best practices to ensure the safety and effectiveness of shotcrete application in underground mines. This includes the implementation of strict safety protocols, the proper use of PPEs, adequate worker training and regular monitoring of working conditions. It also includes proper training on occupational risks, implementing workplace safety practices, carrying out regular risk assessments and raising awareness and promoting a workplace safety culture.

Once the hazards and possible causes of accidents or risks had been identified, the factors that make up the simplified Risk Assessment methodology were quantified. This activity involved risks related to, for example, health, such as the development of lung diseases due to inhaling the silica present in cement. To prevent such risks, it is crucial to implement appropriate prevention measures. This can include the use of PPEs, such as suitable respirators that effectively filter out silica particles, ensuring adequate ventilation of the workplace and providing regular training for workers on the dangers associated with exposure to silica and safe working practices.

5. Conclusions

Shotcrete plays a vital role in stabilizing and protecting structures in underground mines. However, its application presents significant challenges that require careful consideration and planning. By adopting best practices and appropriate safety measures, it is possible to guarantee the effectiveness and safety of shotcrete in underground mining environments.

The use of the GUT Matrix as a risk analysis tool has enabled a systematic and effective approach to identifying, assessing and prioritizing risks, facilitating the implementation of mitigation measures to ensure the safety and effectiveness of this practice.

In this case study, most of the risks are accidental, followed by physical, ergonomic, chemical and biological. With regard to the criteria of the GUT Matrix, the risks were found to have high levels of Severity, high levels of Urgency and low levels of Tendency. The distribution of Tendency values is in the opposite direction to the other two criteria. Based on the obtained results, it can be concluded that the Severity and Urgency values strongly influence the GUT values and that the Tendency values do not. In other words, the greater the Severity of the risk, the greater the Urgency of intervention, thus the greater the prioritization, and the lower the Severity of the risk, the lower the Urgency of intervention, thus the lower the prioritization.

It was also possible to conclude that the greater the Severity of the risk, the greater the Urgency of intervention, but not necessarily a worsening of the situation. On the other hand, the lower the Severity of the risk, the lower the Urgency of intervention, but not necessarily an alleviation of the situation.

Moreover, it should be prioritized the application of measures to prevent fresh concrete fall, detachment and falling rocks, as well as measures to prevent inhalation of dust, fumes and gases during application. In addition, measures should be applied to prevent musculoskeletal injury, bursting of working equipment components and thermal overload. Finally, it is considered essential to carry out surveillance actions to ensure compliance with technical standards of occupational safety.

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