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Article

Exploring industrial hazards and implementing risk control measures in the mining sector

Jianmin Wang, Victor Sifamen*

School of Economics and Management, Anhui University of Science and Technology, Huainan 232002, China
*** Corresponding author:** Victor Sifamen, victor.sekei@hotmail.com

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Abstract: Every sector must possess the ability to identify potential dangers, assess associated risks, and mitigate them to a controllable extent. The mining industry inherently faces significant hazards due to the intricate nature of its systems, processes, and procedures. Effective risk control management and hazard assessment are essential to identify potential adverse events that might lead to hazards, analyze the processes by which these occurrences may transpire, and estimate the extent, importance, and likelihood of negative consequences. (1) The stage of industrial hazard analysis assesses the capability of a risk assessment process by acknowledging that hidden hazards have the potential to generate dangers that are both unknown and beyond control. (2) To mitigate hazards in mines, it is imperative to identify and assess all potentially dangerous circumstances. (3) Upon conducting an analysis and evaluation of the safety risks associated with identified hazards, the acquired knowledge has the potential to assist mine management in making more informed and effective decisions. (4) Frequently employed methods of data collection include interrogation of victims/witnesses and collection of information directly from the accident site. (5) After conducting a thorough analysis and evaluation of the safety hazards associated with hazard identification, the dataset has the potential to assist mine management in making more informed decisions. The study highlights the critical role of management in promoting a strong safety culture and the need for active participation in health and safety systems. By addressing both feared and unknown risks, educating workers, and utilizing safety-related data more effectively, mining companies can significantly improve their risk management strategies and ensure a safer working environment.

Keywords: safety control; mining sector; industrial hazards; risk management; coal

1. Introduction

Mining production is associated with a multitude of risk issues. Some of these principles have broad applicability and may be applied to any firm operating inside the economic system. However, some challenges are specific to mining firms and need a specialized approach throughout the stages of identification, assessment, control, and oversight (Jonek-Kowalska, 2019). The first group of risk factors includes information about the internal environment connected to resources, such as physical and intangible assets, as well as external economic circumstances that affect the operational principles of the sector and the economic rules in place. The second group of risk considerations pertains to conducting a company that relies on the inherent properties of the deposit and the resources contained inside it. These circumstances are exclusive to mining production. These are the primary geological and mining risk factors, including those associated with natural catastrophes linked to mining operations. Many publications and studies in the fields of risk management in mining industries have focused on the geological mining and technological sources of risk associated with mining productivity. These publications and studies demonstrate that both traditional and future mining enterprises have recognized and understood these risks due to centuries of mining experience and rapid technological advancements in the industry (McQuillan et al., 2018).

The growth of the mining sector has a direct impact on governments' resource acquisition and economic growth. The mining sector serves as a major source of revenue for many nations. This industry may be classified within the geological or biochemical sectors, based on certain factors specific to the mining industry (Hussain et al., 2022). While the mining sector has a smaller and less diverse manufacturing setup, it is crucial to comprehend waste disposal methods and develop strategies to minimize mining-generated wastewater at the regulatory level. This is necessary not only to prevent catastrophic accidents but also to protect the local environment and its constituents. The mining business encompasses the many procedures involved in extracting, managing, and manufacturing naturally occurring solid resources from the Earth's surface. Mining has always been one of the most hazardous industries. The validity of these claims is substantiated by statistics provided by reputable organizations such as the State Mining Authority and the OECD (Organization for Economic Co-operation and Development) (Tubis et al., 2020). It is impossible to overlook the strong conclusion that the mining industry may provide, regardless of any possible adverse consequences. The estimated size of the global manufacturing device market in 2019 was 121,694.3 million USD. It is projected to reach a minimum of 165,827.8 million USD by 2027, with a compound annual growth rate (CAGR) of 5.7 percent. Despite being a small batch size with limited interaction with other industry sectors, it shows significant potential for growth. The impact of the mining sector on the global economy is evident when examining its potential market size. In addition, the mining industry has significant influence over the development of other sectors such as energy production, chemical processing, electrical engineering, electronics, and more. Moreover, many of the materials extracted through mining are used for energy generation and serve as raw materials for chemical processing industries (Global Market Insights, 2023) Mining includes rock drilling, milling operations, and dredging. These processes generate large amounts of dust, consisting mostly of crystalline silica. Susceptibility to respirable dust particles is a notable risk factor for several respiratory illnesses. Minimal exposure to respirable dust might lead to upper respiratory tract irritation. Long-term cumulative exposure in workers may lead to occupational asthma, silicosis, silico-tuberculosis, pulmonary tuberculosis (PTB), and obstructive airway disease. HIV and silicosis have been shown to worsen PTB7, along with other inflammatory conditions like bacterial pneumonia, cryptococcosis, enteritis, bronchitis, urinary tract infections, and soft tissue infections. Due to the proximity of asbestos and asbestos-like materials near diamond resources, there is a potential risk of asbestosis, lung cancer, and mesothelioma in mining sites (Nelson, et al., 2011). In addition, the extraction of materials such as concrete clay, limestone, sand, gypsum, gravel, and other essential components used in cement manufacture might potentially expose workers to airborne particles of dust. Studies have shown that cement dust particles may cause indirect harm to the blood system. This harm can manifest as irregular blood cell counts, slight anomalies in chromosomes, a decrease in the rate of cell division, and an increase in the frequency of genetic exchanges between sister chromatids (Utembe et al., 2015). Despite the inherent dangers and risks associated with the mining business, including hazardous conduct, dangerous settings, and unsafe components, many governments see the mining sector as a significant driver of economic development (Qi et al., 2019). The mining process is often regarded as the most detrimental mechanism owing to its complex workflow. According to the MSHA's data on deaths, roof collapses, accidents caused by trips and slides, and incidents involving motorized haulage, including falls on the face, rib, side, or high wall, are the most frequent causes of death. When comparing the amount of deaths with other sectors, coal mining might be considered one of the most dangerous industries. The graph illustrates a decrease in death rates between 2017 and 2019 due to the use of new technology in coal mining. The mining industry plays a vital role in the global economy. Since 2010, the market price of coal mines has seen significant variability. The market value of the company increased to 1.3 billion US dollars in 2011 but then declined to 571 million US dollars by 2015. By the year 2020, the market price fluctuated between the range of 698 million US dollars (Matloob et al., 2021). There are several risks involved with mining activities, including the use of resources and the relationship between the mining system and its environment. These risks emerge from the intense extraction and processing that have a significant influence on the economy. Therefore, it is important to comprehend the principles of risk analysis, appraisal, and control management in this sector, particularly concerning environmental, social, and economic aspects. Consequently, there will be a growing need for new publications and research in this area, especially in affluent nations such as Asia and North America. Mines faced several dangers due to their intricate nature as human-engineered systems. Many individuals often lose their lives and suffer from health issues due to this hazardous situation (Kowalska, 2014). It is important to emphasize that these repercussions may affect both the environment and mine personnel.

The psychometric paradigm was introduced in the 1970s and 1980s to understand why non-experts assess the risk associated with different technologies, services, and vocations differently from specialists (Alrawad et al., 2022). The model suggested that the latter should provide a comprehensive risk assessment by evaluating the probability, consequences, and exacerbation of unforeseen events. In contrast, the latter often rely on subjective evaluations of danger, which means their appraisal of risk is heavily impacted by factors such as attitudes, beliefs, institutions, psychology, society, and culture. The model also proposed nine variables, including individual knowledge, novelty, scientific knowledge, prevalence, immediacy, control, chronicity, voluntariness, and severity, that might influence an individual's perspective. These were also believed to accurately reflect the intricacy of individuals' risk perceptions.

Research on applications has shown the need to consider risk in mining from strategic, operational, and human perspectives. Therefore, to enhance safety, the mining sector is increasingly placing great importance on risk management. Effective mining risk management relies on risk control management, since the outcomes of the risk assessment process aid mine supervision in determining the control measures to be implemented for minimizing mining-related hazards. With the legal need for risk assessment in mines, the maintenance of a safe working environment is now even more reliant on it. The industrial hazard analysis stage determines the ability of a risk assessment procedure to identify and manage potential problems that have not yet been found. It is important to identify and acknowledge all potentially hazardous situations to effectively mitigate risks in mining operations. Identifying all potentially hazardous situations is crucial for effectively managing risks in mining operations. While safety-related tasks such as earlier exams and danger identification have often been neglected, data from interviewing catastrophe victims and survivors, as well as evidence from the accident site, have been routinely used. The information has the potential to enhance the decision-making process of mine managers by facilitating the analysis and evaluation of safety problems via hazard identification. By fulfilling these tasks, the research aims to provide a comprehensive approach to managing risks in the mining sector, ultimately leading to a safer working environment for miners.

2. Literature review

This article examines the role and placement of risk-based thinking in the occupational safety and health (OSH) processes now used by mining businesses. The text provides a concise overview of supply network design, including an examination of existing business requirements and challenges. Evidence has shown that, despite efforts such as implementing activities, occupational accidents in the mining sector remain a significant concern. It is important to thoroughly examine and assess these incidents considering the intricate nature of the business. The study aims to demonstrate the effectiveness of implementing this approach in a business engaged in open-pit mining operations. Additionally, it seeks to monitor the progress of risk-based reasoning in quality management systems toward OSH management procedures. OSH risks were assessed using the matrix approach and Fine and Kinney's technique. Similarly, OSH time and opportunity were evaluated using the list of requirements technique and a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis. The study's results demonstrate that using a risk-based strategy inside an OSH management framework may be a dependable and efficient method for developing and evaluating OSH. The research presents an evaluation of dragline operators and explores possible applications for the information on occupational safety and health (OSH) risks and uncertainties that have been identified during OSH operations. The last portion of the report also provides commentary and analysis on the many hazards that contemporary mining enterprises must confront. Nevertheless, senior executives would assess both the hazards and the possibilities of the OSH management framework as a whole entity. The assessment is now in progress, and talks are still underway (Rudakov, 2020).

Unsafe conduct plays a major role in these cases, as described by accident causation theories. The study utilizes a situational analysis in the Chinese building construction industry to examine the behavioral risk sequences of disasters within the framework of complex network (CN) theories. It considers the limitation that existing research tends to focus on the connections between risky behaviors in accidents. At first, accident occurrences are collected from official websites, and the hazardous actions are then classified using a checklist that relies on several safety rules, including operational requirements. Once the rules for constructing behavioral and environmental networks have been established, a behavioral risk chain network of accidents (BRCNA) is formed. The network structure is constructed using Pajek as an extra tool. The BRCNA performs calculations and assessments of the topological properties. The results indicate that the BRCNA exhibits both scale-free and small-world network properties. The specific findings indicate that the BRCNA may be resistant to random acts of violence. Additionally, behavioral risk has a slightly higher ability to spread and disperse within the BRCNA. This highlights the importance of closely monitoring safety hazards and coordinating efforts to monitor occupational accidents that are linked to these hazards. The prevention of accidents in the construction industry is of paramount importance, both in terms of theoretical understanding and practical implementation. Furthermore, it demonstrates the persistence of some occurrences in China, even with the enforcement of behavioral occupational safety measures by construction enterprises. If the nodes with higher levels were attacked simultaneously, the whole network would become vulnerable and divided into several distinct subnetworks (Guo et al., 2020).

Heightened incidences of work-related injuries have led to many deficiencies inside organizations. In 2017, the European Union (EU) recorded a total of 3,315,101 non-fatal incidents. Multiple sovereign states have seen an increase in the occurrence of injuries. Moreover, the increase in occurrences tends to be concentrated in a small number of businesses and is mostly caused by the rise in rates of occurrence rather than the growth of the workforce. Indeed, organizations in these businesses have implemented less stringent preventive measures compared to those in other industries. Conducting a statistical study of both deadly and non-fatal episodes is of utmost importance. The assessment enhances managers' comprehension of the significance of using preventive and control strategies across enterprises. The researchers gathered data for this study from the National Institute of Statistics (NIS) of Romania, the Labor Inspection in Romania, and Eurostat of the European Commission. Evaluations of the dataset were conducted for both Romanian and EU contexts. The industrial dataset has been subjected to a qualitative assessment. *T*-tests and analysis of variance (ANOVA) were conducted to establish the relationships between the recurrence indices of fatal and non-fatal occurrences, as well as the chosen categories. Men have had much better outcomes compared to women in the workforce. A proposed method for preventing and handling occupational injuries is based on the results of a qualitative evaluation, as well as national and European legislation. An assessment is conducted on the state of workplace injuries in Romania and Bulgaria, both member states of the European Union, focusing on the industrial, construction, transportation, and storage industries. During the period from 2018 to 2020, many patterns were identified. The Romanian Labor Inspectorate primarily depends on the conclusions of the research of the series data to build strategic initiatives (Ivascu and Cioca, 2019).

One significant barrier to economic progress worldwide is meeting the growing energy demands of society. Currently, it is crucial to increase energy consumption to improve living circumstances, job opportunities, and the growth of different industries. Additionally, this is necessary to meet the demands for scientific and technical progress. An assessment of the impact of coal operations on the environment reveals that as worldwide economic development increases, the human impact on the environment also intensifies. The inquiry aims to assess environmental protection in manufacturing since there is a clear decrease in rock mass during underground coal mining. This research investigates the magnitude of the detrimental environmental impacts caused by the coal industry. The importance of occupational risks is shown to be directly connected to the primary statistical component that impacts the accident rate. It has been shown that the technique of estimating the severity of rock falls has to be improved since there is a consistent decline in the incidence of fatal accidents among coal mine workers. During this method, it will be important to use data from multifunctional safety systems (MSS) to analyze occupational risk. The study demonstrates the effective control of mountain pressure during the advancement of a coal seam in the Barentsburg field using advanced techniques such as computer modeling, geo-mechanical analysis, and geophysical methodologies for mine conservation and improvement (Rudakov et al., 2021).

Tsopa et al. (2022) emphasized the importance of reducing the hazards associated with one's career in order to improve the safety of dump truck drivers working in the mining industry. According to Tsopa et al. (2022), the purpose of this research is to enhance the whole transportation process by examining a variety of risk variables and putting strategic safety measures into place. This will eventually result in improved protection for drivers participating in mining activities.

The objective of the present research was to investigate the connections between the organizational and human factors that led to mining accidents. This research used the human factors assessment and classification system (HFACS) in conjunction with a Bayesian network (BN) to analyze the many elements that lead to mining accidents. The BN was constructed based on the hierarchical structure of HFACS. The relevant data for this study was obtained from a total of 295 cases of Iranian mining accidents, which were then collected and analyzed using HFACS. Subsequently, the expectation-maximization method was used to compute the posterior distribution of the contributing factors. To determine the most efficient intervention strategy, sensitivity analysis has been used to assess if various contributing factors had a more significant influence on risky behaviors. The study showed that the occurrences before had greater relative importance for errors related to skills, regular violations, environmental factors, and deliberate inappropriate actions. Furthermore, the sensitivity analysis reveals that the variables associated with the environment and the inability to address acknowledged concerns, such as the persons involved, have a more significant influence on dangerous behaviors. The study's results may guide health and safety procedures by introducing sustainable management approaches aimed at reducing mining deaths. The integration of HFACS with BN proved to be an effective quantitative tool for analyzing the importance of organizational and human factors in mining accidents. By using HFACS (Human Factors Analysis and Classification System) and BN (Bayesian Network) to examine 295 mining occurrences, researchers found that planned inappropriate operations, frequent violations, and external variables, such as skill-based mistakes, were identified as very significant factors in the present study. Furthermore, the process of parameter estimate revealed that environmental variables, inability to address acknowledged difficulties, and human factors had a substantial influence on dangerous actions (Mirzaei Aliabadi et al., 2018).

Smith and Johnson (2024) conducted research that demonstrated the use of sophisticated data analytics in mining operations to predict and mitigate possible threats directly in real time. Research has demonstrated that implementing innovative safety training programs can significantly enhance workers' awareness of potential dangers and their ability to respond promptly. As a result, there is a reduction in the number of accidents that occur during mining activities (Garcia et al., 2023).

The mining industry is gradually acknowledging the importance of comprehensive risk assessments that utilize both qualitative and quantitative data for efficient risk management (Lee and Kim, 2022). The use of machine learning algorithms in the examination of accident data from the past (Brown et al., 2023) has resulted in the dissemination of fresh information on the prevention of accidents in the mining sector in the future. Recently, Nguyen and Patel (2023) conducted an investigation that demonstrated the effectiveness of collaborative solutions, involving workers, management, and safety professionals, in addressing complex safety concerns in the mining industry.

3. Method

3.1. Data collection techniques

The primary method of data collection was through questionnaires. These questionnaires were likely designed to gather information on various aspects related to safety incidents and accidents in the mining industry. Additionally, accident data and incident investigations were obtained from the Directorate General of Mine Safety (DGMS) and Coal India Limited.

3.2. Sample size

The population under study included data from the DGMS and Coal India Limited covering the period from 2000 to 2020.

3.3. Dataset

During the course of the descriptive study technique, a cross-sectional evaluation was carried out. In order to gather data, the questionnaire was the primary method that was used. Consequently, the data that was gathered for this study was used in order to accurately outline the population during the time that it was the subject of examination. When it came to accomplishing its goals, the study relied mostly on a quantitative research approach. In order to determine whether or not the study purpose was met, the research gathered accident data and incident investigations from the DGMS and Coal India Limited. These investigations included inspection assessments. Coal India Limited is a coal mining company that is controlled by the state, while the Directorate General of Mine Safety (DGMS) is a regulatory organization that falls under the Ministry of Labor and Employment in India. Its primary responsibility is to handle concerns about occupational safety, healthcare, and security for individuals who are employed in mines. The statistics that were acquired from the year 2000 to the year 2020 include the mean values for fatal accidents, major accidents, fatality rate, and severe injury rate (Chap13AnnualReport, 2021).

3.4. Data analysis procedures

The collected data underwent a classification process to organize and analyze it effectively. The information was encoded and classified into 17 user-centered categories, further organized into four main subjects: the wounded, task/activity, technology, and damage. The classification process likely involved analyzing the contents of relevant reports and publications to determine the appropriate categories. Additionally, accident categorization codes from the Department of Natural Resources and Mines (DNRM) and the Mine Safety and Health Administration (MSHA) were used to assign codes to the data. Continuous improvement of the codes was carried out through comparison and refinement.

3.5. Classification of data

The next stage involves encoding the information to classify it after the relevant reports have been selected. The study objectives, chosen records' contents, and relevant publications were analyzed. It was discovered that the data could be classified into 17 user-centered categories. These categories were further organized into four main subjects: the wounded, task/activity, technology, and damage. This classification can be seen in **Table 1**. The number of codes for each category has been determined using the accident categorization codes from the Department of Natural Resources and Mines (DNRM) and the Mine Safety and Health Administration (MSHA). After reading the data (Lewis-Beck et al., 2004), the codes underwent continuous improvement by comparison.

Table 1. Areas and categories investigated in the records.

Areas			
Affected	Activities	Machinery	Injuries
Age	Working area	Involvement of machinery	Time of accident
Experience in work	Time of shift	Types of machinery	Week
Type of work	Working hours	-	Injured body part
Title of job	Performed activity	-	Type of injury

Data analysis

The questionnaires were arranged in a way that would make processing and analysis as effective as possible.

3.6. Investigation of industrial hazards

A univariate analysis was conducted in each category, without considering potential combinations. Descriptive analytics were used to identify overarching patterns and trends that aligned with the study's aims.

Are there any more trends in the characteristics of the wounded individual that need further examination? If such is the case, which specific characteristics should be considered?

There is a disagreement among experts in the area on the impact of a worker's characteristics on the frequency of injuries in the workplace. Although there is disagreement among other specialists, several have established correlations between this factor and the severity of an injury, as well as the age and degree of experience of the victim. Given the steady growth of the industry resulting from the expansion of operational processes and the initiation of new activities, it is crucial to examine the characteristics of the wounded individuals. This increase has led to a substantial labor turnover rate, as experienced personnel in older mining operations depart and are replaced by new, less qualified individuals (Amponsah-Tawiah et al., 2016). Interventions might have been used to specifically address susceptible groups by examining accident histories, which would include employee characteristics.

Is the work currently being performed still considered a significant priority? If such is the case, which specific locations should be considered?

Based on specific research, some occupations and duties inside mining businesses were shown to be more hazardous than others, hence raising the probability of miners experiencing injuries. Multiple studies have also shown disparities in accident rates across different occupational categories and have identified certain occupations that need special attention. When combined with other categories, categorizing the ongoing activity might provide valuable data. For example, it might allow a safety officer to determine the kind of job that is most often associated with an accident that affects a certain part of the body (Randolph and Boldt, 1996).

Is the correlation between injuries and drilling equipment still a prominent concern? If the answer is affirmative, which equipment types should be prioritized?

Extensive studies have been conducted on the role of mining equipment in accidents. Certain researchers have identified certain mobile mining equipment as being of paramount significance. It was feasible to evaluate whether the situation in India conformed to the prevailing trend or diverged in some aspects, given the accident investigation records included information on the equipment. This may include information on the specific equipment categories that should have been given higher priority for further investigation, along with precautionary measures (Ruff et al., 2010).

Are there specific characteristics of the damage that need immediate attention in research? If the answer is affirmative, which specific issues still need consideration?

Discoveries are made on the different causes of both fatal and nonfatal accidents. Several individuals have previously seen the necessity to treat certain body locations, damage processes, and sorts of accidents. By analyzing the characteristics of the damage, one may have identified significant trends that need future investigation (Lind, 2008). For instance, it is feasible to determine the priority anatomical regions, the method of injury, the quantity and kind of damage, as well as the accident category associated with a specific incident. In addition, when combined with other attributes, the characteristics of the damage might provide supplementary pertinent information and indicate specific crucial regions.

3.7. Risk control management

A psychometric paradigm approach

If there is only a weak association between the sense of danger and the number of deaths caused by a disaster. The psychometric paradigm was developed with the purpose of offering a solution (Fischhoff et al., 2016). This technique aimed to elucidate the reasons behind the divergent views that individuals have about various hazards. In studies utilizing the psychometric technique to analyze risk perception, respondents evaluate various hazards based on multiple parameters. These parameters include the novelty of the hazard (i.e., whether the risks are new or familiar) and the level of understanding and awareness regarding the potential consequences and scientific knowledge of the threat. An array of hazards with varying characteristics was also examined. Most of the analyses used aggregated data from all study participants. The results of the psychometric paradigm suggest that most qualitative risk indicators used to describe a hazard are connected with, if not strongly correlated to each other. The associations seen between rating scales in most studies may be explained by two primary factors. The primary element was categorized as a danger of dread. The main element exhibited significant connections with rating measures measuring felt dread potential, tragic implications, and loss of control. The unidentified peril was allocated to the secondary primary element. The second component had a robust association with the rating scales measuring perceived freshness, perceived scientific knowledge, and delay of the effects. The public's perception of the risks associated with a hazard may be adequately described by two factors: fear of the known risks and uncertainty about the unknown risks. The risks are located in the region that divides the two main component analyses, namely fear risk and unidentified risk, inside a cognitive map. This cognitive map serves as the fundamental outcome of the psychometric paradigm and is also a symbol of risk disclosure research. The psychometric paradigm facilitates the understanding of why laypeople exhibit concern about some hazards over others. They get high-risk evaluations from the general population in this manner. Hazards are seen as ordinary and lacking in terror. Consequently, these hazards are seen as relatively benign. The presence of dissimilarities in risk perception across participants in research within the history of the psychometric paradigm would render it unacceptable to assess aggregated information. However, research has shown that there are significant discrepancies among individuals in their perception of threat. To effectively ascertain individuals' choices, it is important to understand the elements that contribute to the differences in how risks are perceived on an individual level.

4. Result analysis

4.1. Result presentation

The reliability of each component is evaluated using standardized factor loadings. The results shown in **Table 2** and **Figures 1** and **2** indicate that the factor loadings for the items used to measure the various constructs were more than 0.55. This cutoff value is recommended by Fornell and Larcker (1981) in their publications. The concurrent validity of the measuring items variables was evaluated using the Average Variance Extracted (Average VE), Cronbach alpha, and Composite Reliability (CR). **Table 1** displays the data indicating that the Cronbach Alpha score of the items exceeds 0.70. This illustrates that the structures conform to defined standard of 0.60 and exhibit internal consistency (Hagen and Waldeck, 2014). The criteria set by Nunnally and Bernstein (1978) were met by the stipulated norms for composite dependability, which is 0.7, as seen in **Table 2**.

Table 2. Cronbach's alpha values, factor loadings, average variance extracted, and composite reliabilities.

Study variables		**Employee responsibility**			**Occupation security**		**Management security practices**			**Security programs**	
Indicators		ER1	ER2	ER3	OS1	OS2	MSP1	MSP2	MSP3	SP1	SP2
Factors loading	ER	0.673	0.753	0.732	0.367	0.271	0.409	0.466	0.402	0.436	0.276
	OS	0.336	0.394	0.295	0.835	0.734	0.483	0.541	0.483	0.549	0.381
	MSP	0.314	0.465	0.310	0.567	0.459	0.739	0.735	0.726	0.625	0.556
	SP	0.199	0.398	0.220	0.516	0.346	0.598	0.392	0.526	0.889	0.848
C A		0.810			0.818		0.853			0.836	
rho_A		0.823			0.827		0.855			0.871	
C R		0.863			0.880		0.892			0.901	
Average VE		0.512			0.646		0.577			0.750	

CR = Composite Reliability, CA = Cronbach's Alpha, Average VE = Average Variance Extracted.

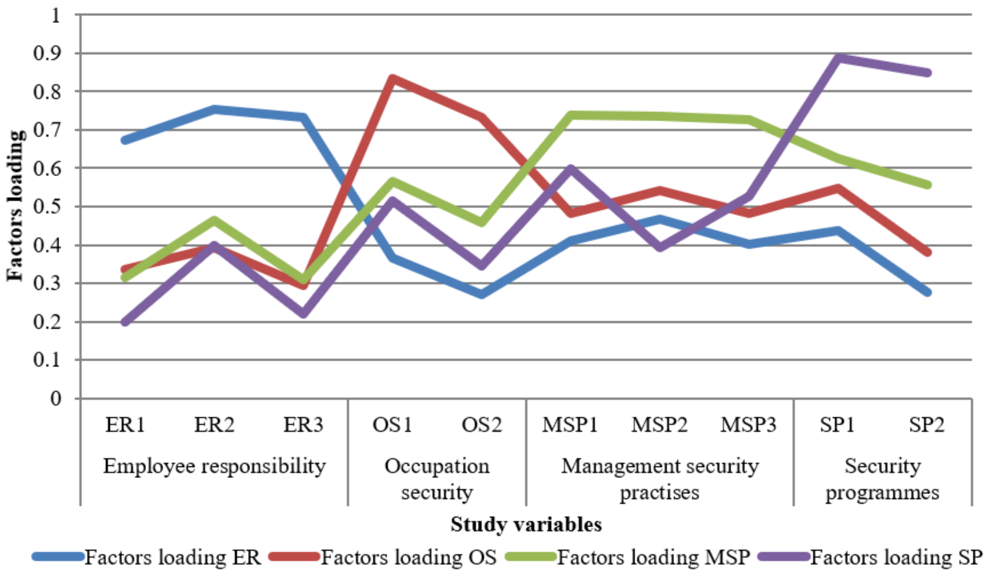

Figure 1. Factors loading validity of convergent.

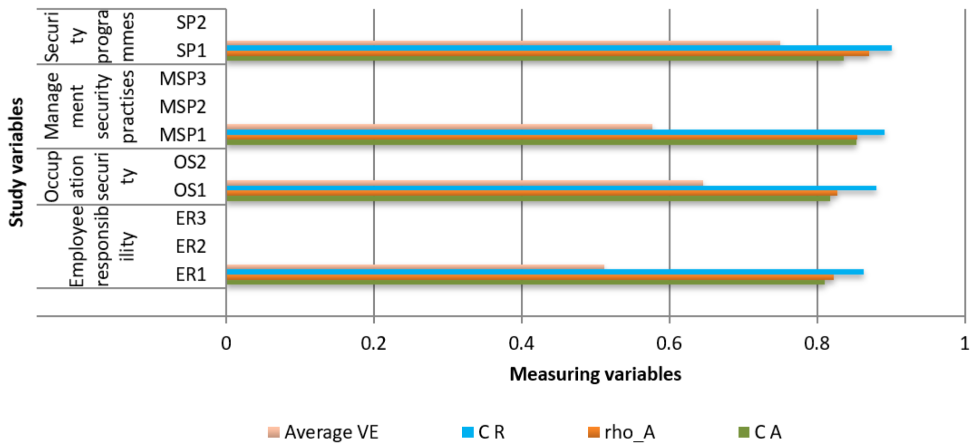

Figure 2. Cronbach's alpha values, and average variance extracted reliabilities.

4.2. Validity of discriminant

Discriminant validity pertains to the degree to which an item may distinguish between many ideas. Discriminant validity suggests that the squared value of Average

VE should be greater than the correlation between two latent variables, as proposed by Larcker and Fornell in 1981. The square root of the Average VE has a much greater magnitude compared to the correlation factor with other components, as seen in **Table 3**. Therefore, the discriminant validity is confirmed, indicating that each latent variable has unique attributes. Furthermore, the Heterotrait-Monotrait Proportion (HTMT) values shown in **Table 4** fall below the accepted benchmarks of 85 as defined by Kline (2011). This indicates that the variables in the study exhibit discriminant validity.

Table 3. Fornell-Larcker principle of discriminant validity.

	Employee responsibility	**Occupation security**	**Management security practices**	**Security program**
Employee responsibility	0.716			
Occupation security	0.464	0.805		
Management security practices	0.553	0.650	0.760	
Security program	0.389	0.546	0.670	0.867

Table 4. Heterotrait-Monotrait proportion (HTMT).

	Employee responsibility	**Occupation security**	**Management security practices**
Employee responsibility			
Occupation security	0.548		
Management security practices	0.645	0.772	
Security program	0.433	0.638	0.780

4.3. Predictive ability and path coefficients

Table 5 presents the R2 values, significance level, and path coefficients of the different structures. The study findings indicated that all approaches, save for the direct association between employee devotion to safety initiatives, are significant. The paths listed in parentheses are significant at different levels of statistical significance. Specifically, the relationship between Management Security Practices and Employee responsibility has a coefficient of 0.432 and is significant at the $p < 0.001$ level. The relationship between Management Security Practices and Job Security has a coefficient of 0.516 and is also significant at the $p < 0.001$ level. The relationship between Occupation Security and Employee Responsibility has a coefficient of 0.184 and is significant at the $p < 0.01$ level. Lastly, the relationship between Security Programs and Occupation Security has a coefficient of 0.200 and is significant at the $p < 0.05$ level. However, only one insignificant route (from Security Programs to Employee Responsibility with a coefficient of 0.001 and a p-value greater than 0.05) was identified. The R2 values for job security about the endogenous latent variables (employee responsibility) were 0.443 and 0.323, respectively. This indicates that 44.4% of the variability in job security may be ascribed to the implementation of safety policies and programs by the management of the institutions. In addition, the combined impact of management participation accounted for 32.4% of the variability in employee dedication to safety, safety initiatives, and occupational safety.

Table 5. '*T*' values result of hypothesis testing through bootstrapping and path coefficients with their bootstrap values.

	OS to ER	MSP to ER	MSP to OS	SP to ER	SP to OS
Original sample	0.184	0.432	0.516	0.001	0.200
Sample mean	0.182	0.435	0.514	0.006	0.204
Standard deviation	0.062	0.070	0.068	0.060	0.080
T Statistics	2.994	6.211	7.549	0.021	2.506
P values	0.004	0.000	0.000	0.985	0.014

4.4. Analysis

Table 6 presents the p-values, confidence ranges, and indirect impact coefficients for the mediating effects of workplace safety. The results indicated that there was a somewhat positive indirect link between management security measures and employee empowerment regarding work safety, acting as mediators (MSP, JS, EC, = 0.095, p = 0.050). This is corroborated by the assertion that employee dedication and management safety policies are mutually reliant. Conversely, it was shown that safety initiatives had a substantial positive impact on occupational safety, thereby enhancing employee commitment (SP, JS, EC, = 0.037, p = 0.050). Job security acts as a mediator between safety measures and employee commitment, as stated.

Table 6. Examination of mediation.

	MSP to OS to ER	SP to OS to ER
Original sample	0.095	0.037
Sample mean	0.095	0.037
Standard deviation	0.039	0.019
T statistics	2.494	2.019
P values	0.014	0.045

Out of the 300 event investigation records, a selection of 150 injury reports with different symptoms and levels of severity were selected for categorizing and coding.

Do other patterns exist in the characteristics of the wounded individual that need more investigation? If such is the case, which specific characteristics should be considered?

Table 7 demonstrates that there were only minor differences in variances. However, the age and experience of the injured workers reveal discrepancies in their knowledge of subterranean locations, particularly among operator/contractor people. Consequently, the age distribution of the miners who were impacted seems to be in proportion. This leads to a rise in the percentage of employees aged 18 to 27 who are wounded, reaching a peak between the ages of 38 and 47. Additionally, there is a decrease in the percentage of workers who are hurt between the ages of 38 and 47, compared to those who are older than 58 years. Over 30% of the surveys lacked aging data, with a higher occurrence in deep mines compared to mining sites, regardless of whether the operators were employees or contractors. The bulk of documents did not include information on the job history of the injured miners, categorized by age group. The focus was mostly on controllers rather than subcontractors, and subterranean mines rather than surface mines. Such data would have enhanced the comprehension of the information. Given the existence of this knowledge gap, the figures demonstrate that workers with less experience were more prone to injuries compared to their more skilled counterparts. More than 50% of the damage caused in surface mining events is attributed to mechanics, welders, and truckers, while supervisors, drillers, and blasters are responsible for the bulk of injuries in underground mining occurrences. Mechanics or repairmen are notably more involved in surface accidents, accounting for 22.5 percent of all such incidents, compared to their involvement in subsurface accidents, which stands at 10 percent. The job titles most affected were drillers, laborers, managers, mechanics/repairmen, and truck drivers. In general, it delineates certain job titles that should be considered while prioritizing research and preventive measures.

Table 7. Age and background of affected workers, broken down by occupation and mining types.

Categories	**Workers**	**Contractors**	**Surface**	**Ground**	**Total**
Age					
20–25	10	6	15	4	35
26–30	50	10	5	15	80
31–40	27	6	32	12	77
41–50	3	4	3	1	9
Unknown	2	8	10	22	42
Experience in mining					
1–5	18	4	0	10	32
6–10	29	12	35	5	81
11–15	15	2	20	1	38
16–20	2	5	8	10	25
Unknown	4	2	0	6	12
Mining experience of now					
1–5	18	20	15	12	65
6–10	20	2	4	17	43
11–15	8	1	2	6	17
16–20	2	3	1	0	6
Unknown	30	19	4	9	62
Overall Experience					
1–5	30	18	6	0	54
6–10	18	16	5	2	42
11–15	19	2	0	15	36
16–20	2	4	1	2	9
Unknown	54	12	0	2	68

Is the work currently being performed still considered a significant priority? If such is the case, which specific locations should be considered?

The primary activities leading to accidents in the overall sample were machine repairs and maintenance, use of mobile equipment, clearing/cleaning up, drilling, and manual lifting/lowering. These activities accounted for 51.5 percent of all incidents. Approximately 60% of the underground injuries occurred in the stope mining area and the shaft region. The majority of surface activity occurrences occurred at enterprises, processing facilities, and transport routes. By identifying the actions and places that are most often associated with accidents, a broad framework is established for prioritizing preventive interventions based on their relevance. Nevertheless, as compared to deep mines, a greater proportion of surface miners had an accident after working for eight hours. Based on a further review of the first 8 hours of a whole day, it was shown that the bulk of accidents occurred between 4 and 8 hours into the day. One of the highest numbers of accidents occurred in both surface and subsurface mining throughout the morning. However, there were even more injuries recorded in deep mines during the nighttime shift compared to mining regions.

Is the correlation between injuries and drilling equipment still a primary concern? If the answer is affirmative, which equipment types should be prioritized?

The discovery that a notable proportion of lethal incidents involving mining equipment transpire is in line with prior research. The bulk of surface mining incidents included the usage of haul trucks, components/parts, and nonpower hand tools, such as light vehicles. On the other hand, most subterranean injuries were caused by drill rigs, rock drills/borers, or other earth-moving gear. Commonly identified equipment included mobile machinery such as haul trucks, excavators, graders, and drill rigs. Given the widespread use of these equipment classes in the mining sector, it is not unexpected that they are engaged. Although the structure of component/part subclasses might make it difficult to focus on protective factors, specific intervention strategies can target the provided drill rigs, non-power equipment, light vehicles, and haul trucks. A plethora of recommendations have been proposed to enhance the safety of truck drivers, drawing on extensive studies undertaken on several subcategories of specialized equipment, such as haul trucks.

Should certain features of the injury be given priority in research? If the answer is affirmative, then which specific issues still need consideration?

Deep mines have resulted in a higher number of deaths compared to surface mining when considering the severity or degree of injuries. Based on the analysis of nonfatal injuries, those who had nonfatal accidents in deep mines often had to take a minimum number of days off work, while those who sustained nonfatal injuries at mining sites frequently had their job capabilities restricted. Surface mines have had a higher number of temporary injuries compared to underground mines, however, the percentage of severe disabilities is equal in both kinds of mines. There was a notable disparity in the injuries that necessitated time off, with 84 percent of all injuries occurring in deep mining and 40 percent in surface mining. The trend aligns with previous discoveries. It is not surprising that electrical transportation has been acknowledged as a major concern, considering that earth-moving gear, such as haul trucks, is commonly associated with mishaps in mining operations. The five primary occurrence categories for the whole cohort were product handling, equipment accidents, power haulage incidents, hand tool incidents, and slip/fall accidents. The majority of injuries occurred in both surface and subsurface areas, affecting the hand/finger and numerous body regions. This applies to all forms of injuries. Regarding the kind of injuries, the majority of surface wounds consisted of lacerations, fractures, and multiple injuries.

5. Discussion

The main objective of the research was to enhance and assess the psychometric paradigm as a methodological approach for identifying risk control management and dangers encountered by workers, as well as their perception of risk in the mining sector. The data were analyzed according to the established protocols for assessing psychological advantages. The analysis's most noteworthy discovery is the following one. The results from the combined analysis at a comprehensive level, together with information that focuses on potential risks, provide support for the use of psychometric paradigm studies to assess workers' viewpoints about the study objective as shown in **Table 8**. The results specifically showed that the cognitive model of the workers' viewpoints was shaped by two prominent factors: feared risks and unknown hazards. The two factors together explained 74.5% of the variability in the respondents' evaluations of hazards. The study found that risk factors such as novelty, individual perception of exposure, and voluntary participation were associated with unknown risk variables. Furthermore, risk factors that were associated with fear included often feared variables that were immediate, controllable, and had the potential to have severe or long-lasting effects. Active participation from management is essential for the effectiveness of any health and safety management system. Consequently, a study was conducted to investigate the impact of safety measures implemented by management, particularly in high-risk and accident-prone environments, on employee commitment. This research aims to investigate the relationship between management security practices, security programs, commitment, and work safety as the mediating variable.

Table 8. Comparative analysis of research findings.

Aspect	Current Research	Slovic (1987)	Fischhoff et al. (1978)	Hofmann and Morgeson (1999)	Neal & Griffin (2006)
Objective	Enhance and assess the psychometric paradigm in identifying risk control management, dangers, and workers' risk perceptions in the mining sector.	Identify and analyze the factors that shape public perceptions of risk.	Examine the psychological dimensions of perceived risk, including dread and unknown risks.	Investigate the role of management in promoting safety and its impact on employee commitment and safety performance.	Explore the relationship between safety climate perceptions and safety performance, focusing on management practices and employee commitment.
Methodological Approach	Psychometric paradigm applied to mining sector, analyzing risk perceptions through cognitive models influenced by feared risks and unknown hazards.	Psychometric paradigm analyzing risk perception dimensions such as dread and unknown risks.	Cognitive dimensions of perceived risk assessed through surveys, focusing on various risk factors.	Analysis of management's role in health and safety systems, using surveys and safety performance data.	Survey-based analysis of safety climate perceptions, management safety practices, and their impact on safety performance.
Key Findings	Cognitive model shaped by feared risks and unknown hazards explains 74.5% of variability in hazard evaluations. Unknown risks linked to novelty and exposure; feared risks linked to immediacy and severity.	Two main dimensions: dread (fear, catastrophic potential) and unknown risks (new, unfamiliar).	Identified immediate, controllable, severe risks as feared, and novel, unknown risks as significant in risk perception.	Active management participation critical for effective health and safety management, influencing employee commitment.	Safety climate perceptions mediate the relationship between management practices and safety performance, with commitment playing a key role.

Table 8. (*Continued*).

Aspect	Current Research	Slovic (1987)	Fischhoff et al. (1978)	Hofmann and Morgeson (1999)	Neal & Griffin (2006)
Risk Factors Identified	Unknown risks: novelty, individual perception of exposure, voluntary participation. Feared risks: immediate, controllable, severe, long-lasting effects.	Dread risks: fear, catastrophic potential, severity. Unknown risks: novelty, unfamiliarity.	Feared risks: immediate, severe, controllable. Unknown risks: new, unobservable.	Emphasized the need for management to actively participate in safety measures to enhance commitment and safety outcomes.	Safety climate influenced by management practices, enhancing employee commitment and safety performance.
Management's Role	Emphasized the importance of active management participation in health and safety systems to improve employee commitment and work safety.	Did not focus on management's role directly but highlighted the importance of public trust in risk management.	Suggested that management's communication and control over feared risks can influence public and worker perception positively.	Found that active management involvement is essential for fostering a strong safety culture and enhancing employee commitment.	Highlighted that effective management safety practices and programs are crucial for a positive safety climate and performance.
Implications for Practice	Mining companies should address both feared and unknown risks, implement safety measures, educate workers, and foster management's active role in safety practices.	Effective risk communication and management strategies should address both dread and unknown risks to shape public perception and trust.	Risk communication strategies should consider the psychological dimensions of perceived risks to improve acceptance of safety measures.	Organizations should ensure active management participation in safety practices to improve employee commitment and overall safety performance.	Implementing strong safety climate practices and management commitment can significantly enhance safety performance and employee engagement.

Our research adds to the body of knowledge by applying the psychometric paradigm specifically to the mining sector, providing new insights into miners' risk perceptions and the impact of management practices on safety outcomes. This comparative analysis highlights the consistency of our findings with previous research while also emphasizing the unique contributions our study makes in understanding risk management in the mining industry.

5.1. Key Findings

- Hazard data is categorized into different types, including mechanical, electrical, chemical, structural, human factors, and environmental hazards.
- Mechanical hazards have the highest number of codes, followed by electrical and human factors, suggesting these areas may require more attention in terms of risk management.
- Environmental hazards have the fewest number of codes, indicating potential underemphasis on environmental risk assessment in mining operations.

5.2. Implications

- Understanding the distribution of hazards across different categories can guide prioritization in risk management efforts.
- The higher number of mechanical and electrical hazards underscores the importance of equipment maintenance and electrical safety protocols.
- Human factors, such as worker behavior and training, emerge as significant contributors to hazards, emphasizing the need for comprehensive safety training programs.

- Environmental hazards, although fewer in number, should not be overlooked, as they can have significant ecological and regulatory implications.

These findings highlight the importance of continuous improvement in safety measures to further reduce accidents and injuries in mining operations. The data can inform decision-making processes for mine supervision and management, guiding the implementation of targeted control measures to mitigate identified risks. The detailed interpretation and their implications for risk management in the mining industry. These findings can inform proactive measures to enhance safety and mitigate risks effectively.

6. Conclusion

Every company must monitor risks, analyze dangers, and minimize them. Complex systems, processes, and procedures pose considerable risks to mining corporations. Risk management and hazard identification help identify, assess, and quantify probable adverse occurrences. As a result, proper risk management in mining is essential to improving safety. Supervisors may use risk assessment results to develop effective mining risk control techniques. Risk assessment in mining operations is now legally required, making safe work practices more important. Industrial hazard analysis uncovers unexpected and unresolved risks, proving risk assessment techniques work. Identification and acknowledgement of all hazards on mining sites are essential to risk mitigation. Accident reports from the Directorate General of Mines Safety in India and publicly listed coal mining businesses help identify safety issues that could potentially cause accidents. Mine managers may make better judgments by reviewing this data and considering the safety implications of recognized hazards. Despite underutilization, safety-related data from investigations and risk assessments is useful. Interviews with accident victims and witnesses, as well as accident location data, provide valuable information. Our analysis uses accident data from India's Directorate General of Mines Safety and a public coal mine. This information helps mine managers analyze and evaluate safety concerns uncovered by hazard identification to make better choices. Our holistic approach to mining safety issues makes our research unique. Our work improves risk management practices and perceptions by merging quantitative analysis, qualitative hazard categorization, and psychometric paradigm insights. This helps to maintain mining safety and reduce hazards. Further research should focus on developing and refining complex risk assessment models for mining's particular difficulties. Real-time risk forecasting and mitigation are possible with machine learning and big data analytics. These systems can analyze large datasets from sensor networks, historical accident records, and environmental factors in order to discover patterns and predict future accidents.

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