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Associations of Occupational and Demographic Factors with Cause of Fatalities in the Indian Coal Mining Sector

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Abstract

Mining is recognized as one of the most hazardous industries, where workers face numerous risks, leading to high fatality rates. This study examines fatal accident data from the Directorate General of Mines Safety (DGMS) reports, covering 401 fatal accident descriptions from 2016 to 2022 in both Underground (UG) and Opencast (OC) coal mines in India. The analysis aimed to identify patterns and associations between key risk factors and the causes of fatalities. Separate analyses for UG and OC mines revealed significant associations between job shift and cause of fatalities in both UG ($p = 0.03$) and OC mines ($p < 0.001$), as well as between occupation and cause of fatalities in UG ($p = 0.02$) and OC mines ($p = 0.003$). Transportation machinery was the leading cause of death in OC mines, particularly during night shifts, while ground movement posed the greatest risk in UG mines, especially in the morning and night shifts. Middle-aged workers (26-45 years), particularly general workers and operators, emerged as the most vulnerable groups due to the physically demanding nature of their roles and heightened exposure to hazardous conditions. These findings highlight the need for safety measures tailored to the distinct risks of UG and OC mines, focusing on machine safety, ground stability, and protections for high-risk worker groups.

Major Findings: *The study revealed statistically significant associations between shift and cause of fatality in UG and OC mines. Significant associations were also found between occupation and cause of fatality in both mine types. Additionally, a significant relationship was observed between age and occupation, as well as between shift and occupation, in OC mines.*

Keywords: *Fatality, Data Analysis, Demographic Factors, Mining, Occupational Factors*

1.0 Introduction

Occupational accidents are a critical concern globally, especially in high-risk sectors like mining. According to the International Labour Organization, more than 2.78 million workers die annually from work-related accidents or diseases, with an additional 317 million non-fatal injuries reported each year[1-3]. This alarming rate highlights the urgent need for improved occupational safety measures across industries, particularly in developing countries where fatality rates remain disproportionately high. Furthermore, the economic burden caused by poor safety practices amounts to 4% of the global Gross Domestic Product (GDP), reflecting the wide-reaching consequences[1].

The global distribution of work-related deaths is heavily skewed, with Asia accounting for 65%, followed by Africa and other regions. Fatality rates per 100,000 workers across all industries and sectors in Africa and Asia are 4 to 5 times higher than in Europe, revealing significant regional disparities in overall workplace safety standards and occupational risk management[4]. In India,

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the issue is particularly pronounced as the fatality rate stands at 11.4 per 100,000 workers, and despite ongoing efforts to enhance safety protocols, fatality rates have not seen significant reductions[5]. The coal mining sector, which contributes significantly to India's energy production, is particularly hazardous[6-8]. Between 2013 and 2022, the Directorate General of Mines Safety (DGMS) recorded 604 fatalities in coal mines, indicating the persistently dangerous environment in which miners operate[9].

Despite the existence of various statutory guidelines in India, fatal accidents in the mining sector continue to occur. The Mines Act, of 1952, and its subsequent amendments provide the primary legal foundation for mining safety regulations. The Mines Rules, 1955, offer detailed guidelines for workplace safety protocols and worker protections. The DGMS plays a pivotal role in developing and enforcing these standards through various circulars and guidelines. Critical regulatory documents to highlight include the DGMS Circular No. 13 of 2014, which establishes comprehensive safety management systems. Other important references include the Mines Vocational Training Rules and the Mines Rescue Rules, which provide frameworks for emergency preparedness and worker skill development. Recent policy initiatives like the Mines Sustainable Development Framework demonstrate a holistic approach to safety, emphasizing technological interventions, risk assessment, and worker welfare. The National Mineral Policy, 2019, further reinforces the commitment to improving safety standards in the mining sector.

Despite these statutory guidelines being in place, the mining sector, especially coal extraction, presents a unique set of risks, and fatal accidents are well above what can be termed "As Low as Reasonably Possible" (ALARP). Workers in underground coal mines face the dangers of roof collapses, methane gas explosions, and equipment malfunctions, while opencast mines expose workers to risks from heavy machinery and large-scale blasting operations[10-12]. The fatality rates remain high despite stringent safety guidelines. According to the DGMS, the mean fatality rate in coal mines was 60.4 per year between 2013 and 2022[9]. There is a need for a more nuanced understanding of the factors contributing to these accidents, particularly those related to demographic and occupational aspects. The harsh realities faced by miners are not merely statistics; they represent the lives of individuals and their families impacted by workplace accidents. Miners often work long hours under challenging conditions, where unsafe conditions and unsafe practices can result in tragic outcomes. A more comprehensive approach to understanding workplace fatalities would consider the direct causes and the underlying factors related to workers' backgrounds and job characteristics that could contribute to increased risk. Previous research has shown that factors such as age, work shift, and job role can significantly impact accident rates[13-16]. A study by Gonzalez-Delgado *et al.*, found that male workers, those employed in machine operation roles, and individuals with more than one year of experience were more likely to be involved in fatal occupational accidents[17]. Similarly, younger and less experienced workers are often at higher risk of accidents due to a lack of familiarity with safety procedures, while older workers may face physical limitations that increase their vulnerability in dangerous environments[18].

The present study seeks to uncover the relationships between specific demographic and occupational factors, namely age, work shift, job type, and various causes of workplace fatalities. By analyzing these associations, patterns that may reveal heightened risks for certain groups or in particular work contexts can be identified. Additionally, this study aimed to examine the distribution of immediate causes of workplace fatalities across various demographic and job-related factors in Open Cast (OC) and Underground (UG) mines separately. The study employed the chi-square (χ^2) test to examine the proposed hypotheses. Additionally, Cramer's V was used to assess the associations between various factors[19]. The hypotheses that could not be rejected were subjected to further scrutiny to analyze the distribution of fatalities across different combinations of factor levels. Instead of using tabular formats, various graphical representations were utilized to illustrate these distributions, providing a more visual and intuitive understanding of the research findings.

The findings of the present work will enable the mine management to identify and formulate targeted safety interventions. By understanding which factors are most strongly associated with specific causes of fatalities, safety professionals and employers can develop more precise and effective preventive measures. These tailored strategies could include specialized training programs for vulnerable age groups, enhanced safety protocols for high-risk shifts, or job-specific equipment modifications.

This approach allows for a more efficient allocation of safety resources and a more impactful reduction in workplace fatalities across diverse occupational settings. Our central hypothesis posits that significant associations exist between demographic, occupational characteristics, and immediate causes of fatalities.

1.1 Hypotheses

To further explore the associations among age, job profile, shift timing, and cause of fatalities among deceased workers, the following hypotheses were formulated and tested separately for underground and opencast fatalities:

H1: The age of the deceased is associated with the cause of the fatality. H2: The work shift is associated with the cause of the fatality.

H3: Occupation is associated with the cause of the fatality.

H4: The age of the deceased is associated with their occupation. H5: The work shift is associated with the age of the deceased.

H6: The occupation of the deceased is associated with their work shift.

2.0 Materials and Methods

Figure 1 shows the methodology adopted in the present study.

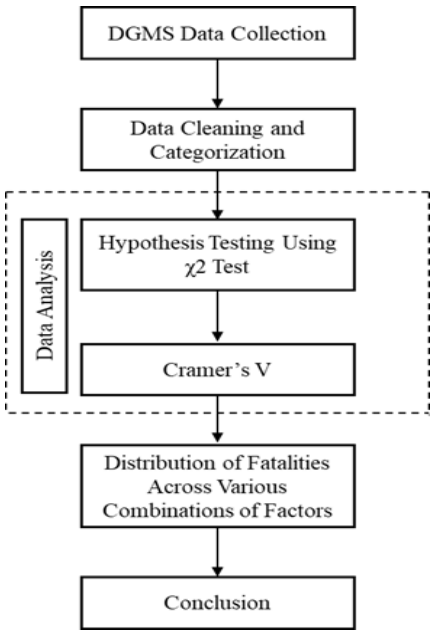


Figure 1. Methodology adopted in the study.

2.1 Data Collection

The study utilized fatality data from the DGMS reports covering the six years from 2016 to 2022, specifically concentrating on coal mines in India[9]. To construct a comprehensive database, the analysis involved systematically extracting detailed information from the collected accident reports. Key information collected included the type of mine (OC and UG), the worker's age, the time of the accident, the occupation of the deceased, and the immediate cause of the fatality. Moreover, a thorough categorization of causes of fatality, and occupation was undertaken. Additionally, the time of the accident was categorized into three shifts. This approach ensured that the database was suitable for further analysis.

2.2 Data Cleaning and Categorization

In the data cleaning process, inconsistent or incomplete records were systematically identified and addressed. Missing data points were excluded from the analysis if they were deemed non-essential. Various classes of data were then categorized according to the coding scheme presented in Table 1.

2.3 Data Analysis

The chi-square test of association serves as a robust statistical tool for evaluating the independence between categorical variables[19]. This non-parametric test quantitatively assesses whether the observed frequency distribution diverges significantly from the expected distribution as dictated by the null hypothesis, which asserts the absence of an association between the variables. The chi- square statistic (χ^2) is computed using the following expression.

$$\chi^2 = \sum \frac{(Oi - Ei)^2}{E_i}$$

Where O_i represents the observed frequencies and E_i denotes the expected frequencies for each category. A significance level of α=0.05 was adopted to evaluate the statistical relevance of the findings.

2.3.1 Cramér's V

Cramér's V quantifies the strength of the relationship between two categorical variables, particularly in the

Table 1. The coding scheme used for variables for data analysis

Age		Shift		Occupation		Cause	
Variable class	**Code**	**Variable class**	**Code**	**Variable class**	**Code**	**Variable class**	**Code**
<25 years	0	6:01 am-2:00 pm	0	Operator	0	Dust, Gas, and others.	0
25-45	1	2:01 pm- 10:00 pm	1	Welder, fitter, electrician	1	Electricity	1
>45	2	10:01 pm-6:00 am	2	Helper, Haulage attendant, Guard	2	Explosive	2
				Blasting crew	3	Falls (other than falling off the ground)	3
				Dresser	4	Ground movement	4
				Executive	5	Machinery (other than transport)	5
				Supervisor	6	Other cause	6
				Support man	7	Transport machinery (non-winding)	7
				General Worker	8	Transport machinery (winding)	8

context of larger contingency tables[19]. This statistic, derived from the chi-square statistic, was normalized to yield a value ranging from 0 to 1, where 0 signified no association and 1 indicated a perfect association. Cramér's V was computed using the following expression.

$$V = \sqrt{\frac{\chi 2}{n(k-1)}}$$

Where n is the total number of observations and k represents the smaller number of categories across the two variables under consideration. In the present study, Cramér's V was calculated to provide insights into the strength of the associations identified through the chi-square test.

2.4 Data Visualization

After testing the proposed hypotheses and identifying significant associations, various visualization techniques were employed to explore the combinations of different classes of risk factors. Pie charts, heat maps, and stacked bar charts were used to visualize the conditional distribution of different variables.

3.0 Results and Discussion

Tables 2 and 3 present the annual fatality statistics for underground (UG) and open-cast (OC) mines, respectively. Analysis of Table 2 reveals that in UG mines, ground movement is the leading cause of fatalities, accounting for 43.75% of deaths, followed by transportation machinery (non- winding) at 16.87%. These two causes alone are responsible for approximately 60% of all fatalities in UG mines. In contrast, Table 3 shows that in OC mines, transportation machinery (non-winding) is the primary cause of fatalities at 42.73%, with machinery other than transportation machinery contributing an additional 19.91%. Together, these two factors account for more than 60% of fatalities in OC mines.

Table 2. Frequency of fatal accidents reported across various occupations in UG coal mines in India from 2016-2022

Cause of Fatality		Year							Total
		2016	2017	2018	2019	2020	2021	2022	
	Dust, Gas, and Other Combustible Material	4	0	3	0	0	0	0	7
	Electricity	0	1	2	1	0	1	0	5
	Explosives	0	1	0	0	2	1	0	4
	Falls (Other than Falls of Ground)	0	4	1	4	2	4	1	16
	Ground Movement	16	9	9	6	8	14	8	70
	Machinery Other than Transp. Machinery	5	1	1	2	0	0	1	10
	Other causes	0	0	0	0	0	0	1	1
	Other Causes	0	4	2	6	5	1	0	18
	Transportation Machinery (Non- Winding)	9	7	3	3	2	2	1	27
	Transportation Machinery (Winding)	1	0	0	1	0	0	0	2
Total		35	27	21	23	19	23	12	160
Percentage		21.87	16.87	13.12	14.37	11.87	14.37	7.5	
Cumulative Percentage		21.87	38.75	51.87	66.25	78.12	92.5	100	

3.1 Association between Demographic, Occupational Factors and Cause of Fatalities

The results of the Chi-square test for the association between various risk factors and causes of fatalities are summarized in Table 4. For OC mines, the analysis indicated significant associations between shift and the cause of fatality ($p < 0.001$) and between occupation and the cause of fatality ($p = 0.003$). Conversely, the relationship between age and the cause of fatality was not significant ($p = 0.34$). However, a significant association was found between age and occupation ($p < 0.001$), while the relationship between age and shift was also not significant ($p = 0.20$). Notably, the association between shift and occupation was significant ($p = 0.001$).

Additionally, the chi-square test results for underground mining revealed significant associations between the shift and the cause of fatality ($p = 0.03$) and between occupation and the cause of fatality ($p = 0.02$). In contrast, the association between age and the cause of fatality was not significant ($p = 0.39$). Furthermore, no significant relationships were observed between age and occupation ($p = 0.38$), as well as between age and shift ($p = 0.96$). The association between shift and occupation also indicated a lack of significant influence ($p = 0.49$).

These findings explain the critical role of shift and occupation as risk factors associated with the cause of fatalities in both underground and opencast mining environments. Specifically, in underground mining, the significant associations between shift and occupation with fatality causes suggest that specific work schedules and job roles may exacerbate risk. This could reflect unique challenges and hazards present during different shifts, such as variations in supervision levels or worker fatigue.

Conversely, although age did not demonstrate a significant relationship with the cause of fatality in either

Table 3. Frequency of fatal accidents reported across various occupations in OC coal mines in India from 2016-2022

Cause of Fatality	Year							Total
	2016	2017	2018	2019	2020	2021	2022	
Dust, Gas, and Other Combustible Material	1	1	1	0	0	0	2	5
Electricity	0	1	3	1	1	2	1	9
Explosives	0	1	2	1	4	1	0	9
Falls (Other than Falls of Ground)	6	0	2	4	4	2	4	22
Ground Movement	23	1	0	5	0	1	3	33
Machinery Other than Transp. Machinery	6	11	12	6	7	4	2	48
Other Causes	3	0	2	1	2	3	0	11
Transportation Machinery (Non- Winding)	19	19	16	14	16	15	4	103
Transportation Machinery (Winding)	0	0	0	1	0	0	0	1
Total	58	34	38	33	34	28	16	241
Percentage	24.06	14.10	15.76	13.70	14.10	11.61	6.63	
Cumulative Percentage	24.06	38.17	53.34	67.63	81.74	93.36	100	

Table 4. Chi-square test results for the association between risk factors and cause of fatality

Variables	UG			OC		
	Chi- square	Cramer's V	p-value	Chi- square	Cramer's V	p-value
Shift vs cause	27.46	0.29	**0.03**	45.03	0.30	**<0.001**
Age vs cause	16.8	0.23	0.39	17.60	0.19	0.34
Occupation vs cause	97.35	0.27	**0.02**	69.0	0.24	0.003
Age vs occupation	19.1	0.24	0.38	34.67	0.27	**<0.001**
Age vs Shift	0.57	0.04	0.96	5.91	0.11	0.20
Shift vs Occupation	17.44	0.23	0.49	29.34	0.24	0.001

mining context, its notable association with occupation in opencast mining implies that older workers may be concentrated in particular job roles, potentially influencing their risk exposure. The lack of significant findings related to age and cause of fatality suggested that workers of all ages are similarly vulnerable to the various causes of fatal accidents in mines. A young worker is not significantly more or less likely to be involved in a specific type of fatal accident compared to an older worker, and vice versa.

3.1.1 Shift vs Cause of Fatality

The analysis of fatality patterns in Open-Cast (OC) and Underground (UG) coal mines offers critical insights into the nature of occupational hazards associated with different shifts. As Figure 1 depicts, in OC mines, the morning shift sees fatalities primarily linked to transportation machinery (non-winding), which accounts for 40.6% of deaths, illustrating the substantial risks posed by heavy equipment during this time. Furthermore, 19.8% of fatalities arise from machinery other than transportation, indicating the threats posed by various operational machinery. As the afternoon shift unfolds, fatalities related to transportation machinery decline slightly to 33.7%; however, there is a significant rise in Other Causes, which contribute to 27% of the total fatalities. During the night shift, fatalities associated with transportation machinery (non-winding) surge to 60.7%, revealing the increased dangers tied to reduced visibility and manpower, highlighting the urgent need for targeted safety interventions.

In contrast, the assessment of UG mines presents a different risk landscape as shown in Figu re 2. The morning shift is dominated by ground movement, responsible for a staggering 50.7% of fatalities, emphasizing the unique geological hazards inherent to underground operations. Transportation machinery (non-winding) follows at 14.7%, underscoring the combined risks from ground instability and machinery. As the afternoon shift progresses, ground movement remains the leading cause but with a reduced share of 29.4%, while fatalities from transportation machinery rise to 19.6%, indicating an evolving risk profile as activity levels increase. The reduction in fatalities due to ground movement in the afternoon shift can be attributed to increased hazard perception and enhanced communication. The night shift once again highlights ground movement, accounting for 51.5% of fatalities, while transportation machinery fatalities climb further to 24.2%, consistent with trends observed in OC mines.

Comparing the two environments reveals stark contrasts in fatality causes. OC mines are primarily affected by machinery-related fatalities, particularly involving transportation machinery, with risks intensifying during night operations due to visibility challenges. Conversely, UG mines face persistent threats from ground movement, which remains a significant hazard throughout different shifts. These findings stress the importance of tailored safety protocols that address the unique challenges of each mining environment. In OC mines, enhancing safety measures for transportation machinery during night shifts is crucial, while in UG mines, reinforcing structural stability and monitoring ground conditions are essential for reducing fatalities associated with geological risks.

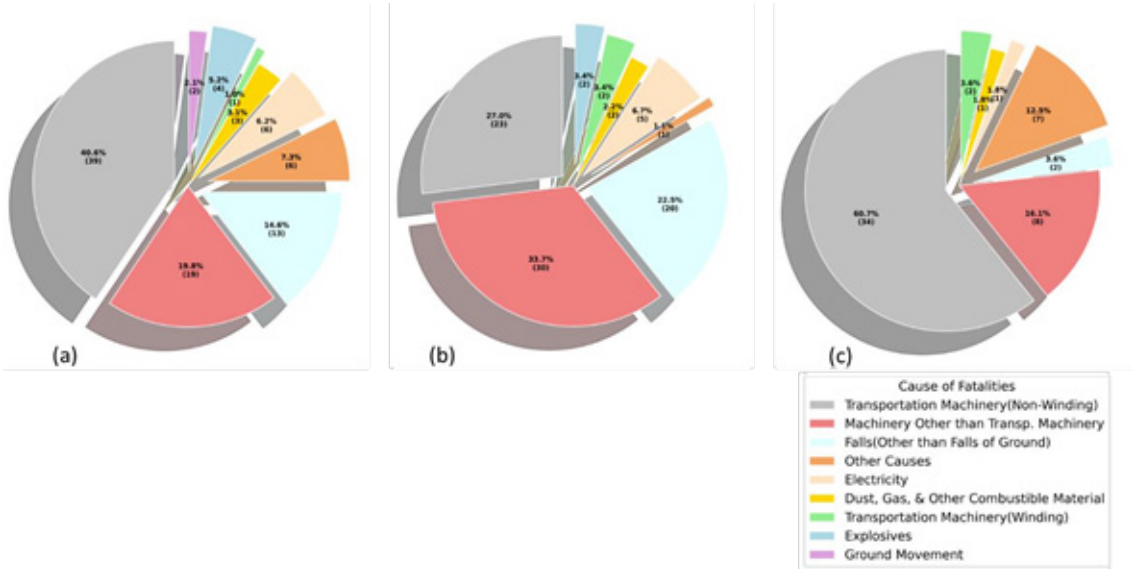


Figure 2. Shift vs causes of fatalities in opencast coal mines **(a)** Morning shift **(b)** Afternoon shift **c)** Night shift.

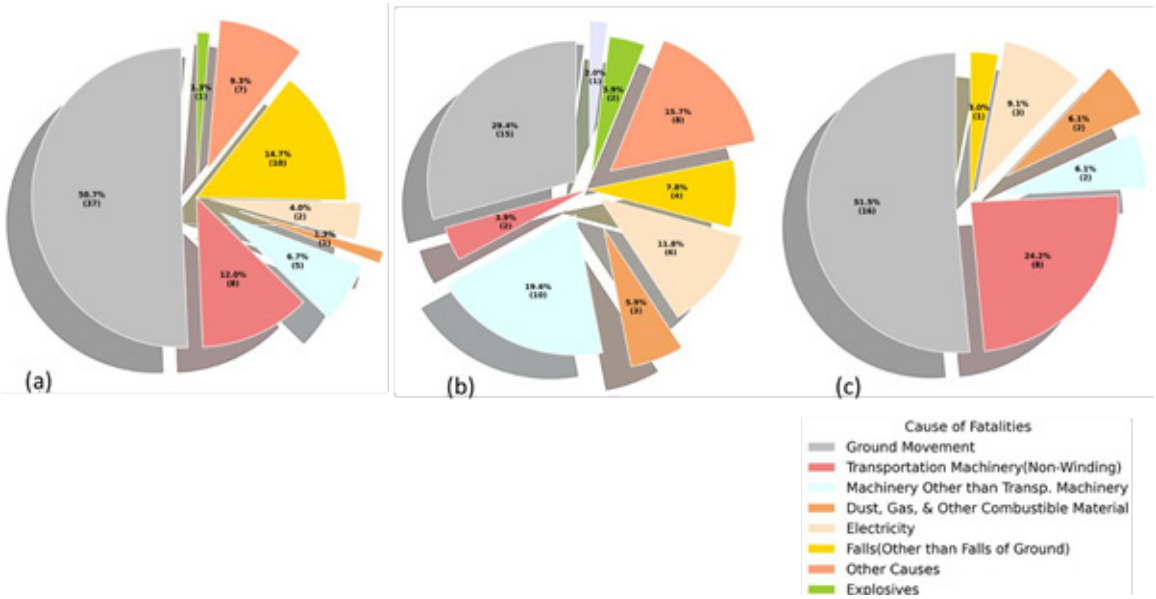


Figure 3. Shift vs occupation of fatalities for UG coal mines; **(a)** Morning shift **(b)** Afternoon shift **(c)** Night shift.

Figure 3 illustrates the distribution of fatalities overtime during the morning shift, revealing an increasing trend in fatalities as time progresses in both UG and OC mines. The peak in fatalities occurs between 12:00 and 14:00, just before the shift ends. This may suggest that workers are in a hurry to finish the shift, which could lead to reduced hazard perception and a lack of communication, potentially contributing to the rise in fatalities. As Figure 4 shows, during the afternoon shift, the highest fatality rate in OC mines is observed between 18:00 and 20:00, a time when reduced illumination may exacerbate hazardous conditions. In contrast, the fatality rate in UG mines remains consistent, as work is always conducted under artificial lighting, eliminating any sudden reduction in illumination and, therefore, preventing an increase in hazard levels. As Figure 5 shows, on the night shift, OC mines experience the most fatalities between 02:00 and 04:00, which could be attributed to diminished awareness and fatigue due to circadian rhythm disruption[20-23]. Also, it has been reported that fatigue and drowsiness can cause lapses of concentration, resulting in accidents and fatalities during the night shift[24]. Implementing an appropriate work-break program, managing sleep disorders, and raising awareness can mitigate the impact of circadian rhythm disturbances and effectively reduce accidents[25].

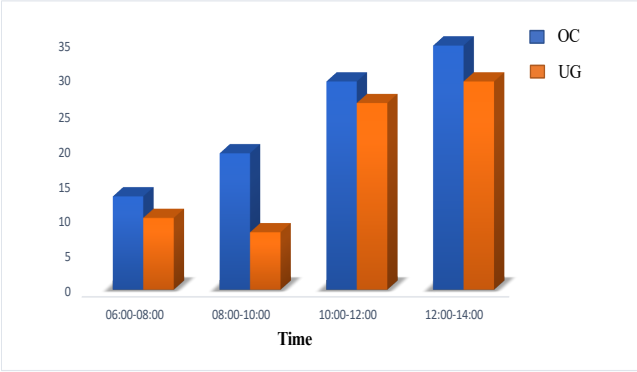


Figure 4. Distribution of fatalities over time in the morning shift.

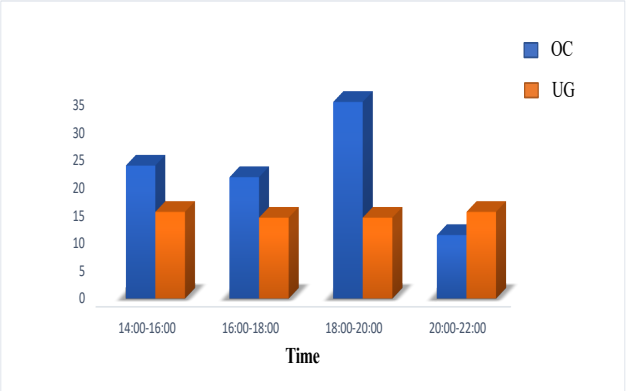


Figure 5. Distribution of fatalities over time in the afternoon shift.

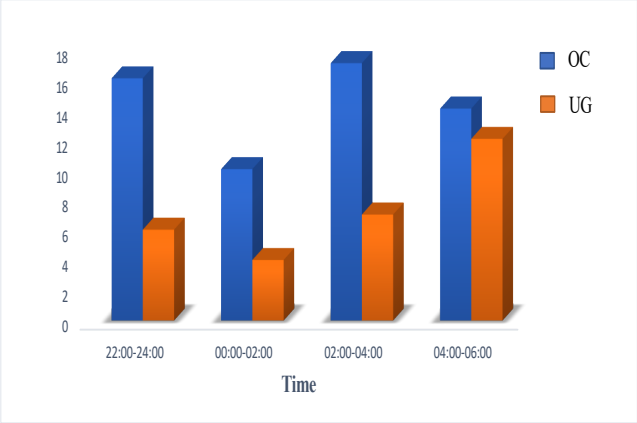


Figure 6. Distribution of fatalities over time in the evening shift.

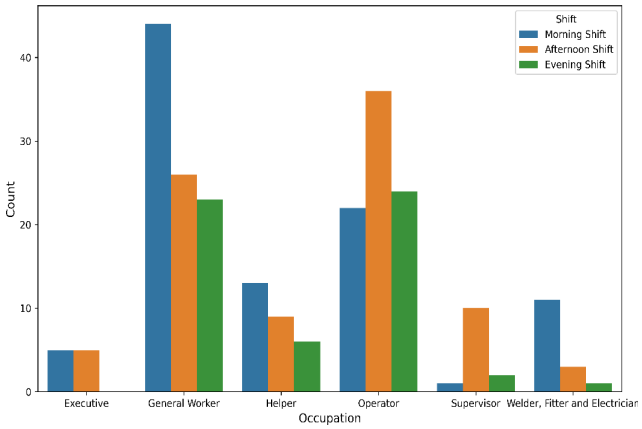


Figure 7. Shift vs occupation of fatalities in opencast mines.

Additionally, implementing a buddy system for high-risk tasks can further reduce risk and help decrease accident rates. Conversely, in UG mines, fatalities peak just before the end of the shift, suggesting that, similar to the morning shift, the rush to complete the shift may result in decreased hazard perception.

Comprehensive safety interventions to mitigate the risk of the night shift should focus on mitigating the unique challenges of night work. This could include implementing enhanced lighting systems with improved visibility technologies, increasing supervisor presence and active monitoring during night shifts, and developing specialized fatigue management protocols. Rotation of workers to prevent extended periods of night work, mandatory rest breaks, and the use of advanced alertness monitoring technologies could help counteract the physiological and cognitive challenges associated with night shifts.

As suggested by Figure 6, in open-cast mines, an interesting pattern emerges when examining fatalities across different work shifts and job roles. Contrary to the trend observed for helpers and general workers, operators experience a higher rate of fatalities during the afternoon shift. Several factors could potentially explain this phenomenon. Firstly, operators may face increased fatigue during afternoon shifts due to the cumulative effects of physical and mental stress from operating heavy machinery throughout the day. Secondly, the afternoon shift might coincide with peak production hours, leading to heightened pressure and potentially riskier decision-making.

3.1.2 Age vs Occupation in OC Mine

Figure 7 reveals that the general workers experienced the highest fatality rates, particularly in the 25-45 age category where 59 fatalities were recorded. This stands out as the most vulnerable group across all occupations and age groups, highlighting the physically demanding nature of their work and the cumulative exposure to hazards. Fatalities among General Workers in the older (>45) and younger (<25) age categories, with 27 and 12 deaths respectively, further emphasize the broad vulnerability within this group, likely due to sustained physical exertion and hazardous work conditions. Operators show a similar but more evenly distributed trend, with 43 fatalities in the 25-45 age group and a comparable number in the >45

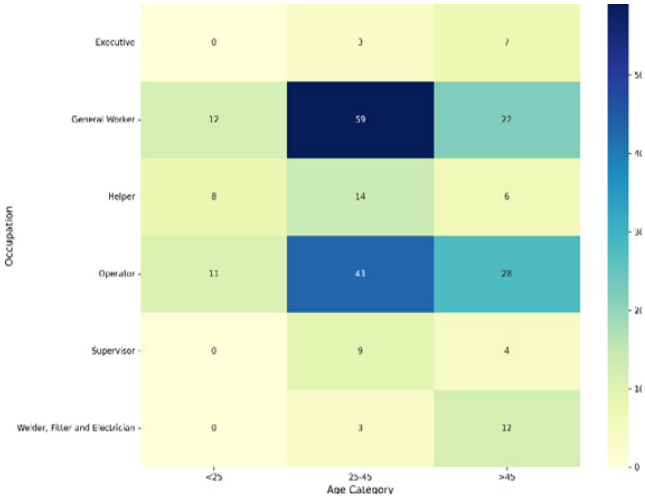


Figure 8. Age vs occupation in opencast mine.

category (28 fatalities). The consistent fatality rates across different age groups suggest that operators face continuous risks throughout their careers, with the middle-aged group potentially bearing more responsibilities, leading to higher exposure to occupational hazards. However, the lack of employment data presents a significant limitation in establishing a causal relationship between age and fatalities in mines.

In contrast, helpers report significantly lower fatalities, with a peak of 14 deaths in the 25-45 age range. Their relatively lower fatality numbers across all age groups suggest that they are exposed to fewer high-risk tasks compared to general workers and Operators, reflecting a less hazardous role within the occupational structure. Other occupations, such as executives, supervisors, and skilled trades like welders, fitters, and electricians, show fewer fatalities overall. However, the higher fatality counts among older workers (>45) in the skilled trades (12 fatalities) point to the physical strain that accumulates with age in these roles.

In summary, the data indicates that middle-aged workers (25-45 years) are particularly at risk, especially in physically demanding roles like general workers and operators. Their higher fatality counts may be linked to increased exposure and responsibility in these roles. Additionally, the elevated fatality rates among older workers (>45) further highlight the cumulative toll of long- term exposure to occupational risks. These findings suggest that targeted interventions should focus on reducing risks for these vulnerable groups to reduce the rate of fatalities in the mining industry.

3.1.3 Occupation and Cause of Fatality

The heatmap reveals significant patterns in fatality rates across different occupations and causes in UG and OC mines as shown in Figure 8 and Figure 9 respectively. In underground mines, general workers show the highest vulnerability, with a notable concentration of fatalities linked to the ground movement (22 fatalities) and falls (other than falls of the ground) (11 fatalities), whereas in opencast mines operators were found to be most susceptible to fatal accidents due to transportation machinery (40 fatalities). This suggests that their physically demanding tasks expose them to greater danger. The consistent exposure to heavy machinery in their daily roles may account for these high fatality



Figure 9. Occupation vs cause of fatalities in underground mines.



Figure 10. Occupation vs cause of fatalities in opencast mines.

rates. In contrast, executives, supervisors, and skilled trades such as welders, fitters, and electricians exhibit lower fatality counts, with fatalities dispersed across various causes, including machinery accidents and ground movement. The reduced fatality rates in these occupations could indicate less direct engagement with hazardous tasks, although ground movement remains a significant concern for Executives, with 7 fatalities recorded.

Overall, the data presents those high-risk occupations like general workers and operators are disproportionately affected by fatalities due to ground instability and machinery-related incidents. While skilled and supervisory roles face fewer fatalities, ground movement hazards continue to pose a significant risk across all job categories. This highlights the need for improved safety measures in managing ground stability and machinery operations.

Overall, these results highlight the need for targeted interventions focusing on work shifts and occupational roles to enhance safety and mitigate fatalities in the mining sector. Further research is warranted to explore the underlying factors that contribute to these associations and to develop effective safety strategies tailored to the unique conditions of underground and opencast mining.

3.2 Limitations

The limitations of the present study stem from two primary sources. First, the dataset provided by the DGMS is inherently incomplete. The fatality dataset lacks critical demographic, personal, and occupational factors, which significantly constrains the depth and breadth of the analysis. Second, the reliance on univariate statistical methods further limits the comprehensive understanding of the data. Despite these methodological and data-related constraints, the study offers valuable insights into the association of various risk factors in coal mines, providing a foundation for future, more nuanced research.

4.0 Conclusion

This research employed statistical hypothesis testing to analyze fatality patterns in mining across variables like shift timing, age groups, occupational roles, and mine types. By conducting an in- depth statistical analysis, the study uncovered significant associations between fatality causes and certain factors, while also identifying no statistically significant link between fatality causes and age. This study underscores the critical links between age, work shifts, job roles, and the causes of fatalities in both oOpencast (OC) and Underground (UG) mining environments. In OC mines, the night shift poses the highest danger, with most fatalities linked to transportation machinery, highlighting the urgent need for enhanced safety measures during low-visibility conditions. In UG mines, ground movement remains the leading cause of fatalities across all shifts, emphasizing the persistent geological risks. Middle-aged workers (23-44 years), especially those in physically demanding roles like general workers and operators, are the most vulnerable to fatal accidents. This is likely due to their exposure to heavy machinery in OC mines and unstable ground conditions in UG mines. The data also shows that older workers in skilled trades are not immune to risks, even though their overall fatality rates are lower, highlighting the impact of long-term exposure to hazardous environments. These findings point to the need for focused safety measures that account for specific job roles and the time of day in both types of mines. In OC mines, particular attention should be given to improving safety around machinery during night shifts. In UG mines, efforts should be directed toward reinforcing ground stability. Additionally, strategies tailored to the needs of middle-aged and older workers will be crucial in reducing fatalities. By implementing these targeted safety interventions, mining operations can significantly reduce risks and create a safer working environment.

5.0 References

1. International Labour Organization. Safety and health at the heart of the future of work: Building on 100 years of experience. International Labour Organization; 2022. Available from: https://www.ilo.org/global/topics/safety-and-health-at-work/lang--en/index.htm
2. Kumar A, Senapati A, Bhattacherjee A, Ghosh A, Chau N. A practical framework to develop and prioritize safety interventions to improve underground coal miners' safety performance. Work. 2024; 77(2):697-709. https://doi.org/10.3233/WOR-230172
3. Senapati A, Bhattacherjee A, Chatterjee S. Causal relationship of some personal and impersonal variates to occupational injuries at continuous miner worksites in underground coal mines. Saf Sci. 2022; 146:105562. https://doi.org/10.1016/j.ssci.2021.105562
4. United Nations Global Compact. Occupational safety and health. United Nations Global Compact. Available from: https://www.unglobalcompact.org/what-is-gc/our- work/social/occupational-safety-and-health
5. Hämäläinen P, Takala J, Kiat TB. Global estimates of occupational accidents and work- related illnesses 2017. World. 2017; 2017:3-4.

6. Geng F, Saleh JH. Challenging the emerging narrative: a critical examination of coal mining safety in China, and recommendations for tackling mining hazards. Saf Sci. 2015; 75:36-48. https://doi.org/10.1016/j.ssci.2015.01.007
7. Martin JE, Rivas T, Matías JM, Taboada J, Argüelles A. A Bayesian network analysis of workplace accidents caused by falls from a height. Saf Sci. 2009; 47(2):206-214. https://doi.org/10.1016/j.ssci.2008.03.004
8. Senapati A, Bhattacherjee A, Chau N. Associations of job-related hazards and personal factors with occupational injuries at continuous miner worksites in underground coal mines: a matched case-control study in Indian coal mine workers. Ind Health. 2020; 58(4):306-317. https://doi.org/10.2486/indhealth.2019-0102
9. DGMS. SANKET Statistical analysis and numbers: key evaluation of trends in coal mine accidents 2016-2022. Ministry of Labour and Employment, Government of India; 2024. Available from: https://www.dgms.gov.in/writereaddata/UploadFile/sanket0404_2024.pdf
10. Kecojevic V, Komljenovic D, Groves W, Radomsky M. An analysis of equipment-related fatal accidents in US mining operations: 1995-2005. Saf Sci. 2007; 45(8):864-874. https://doi.org/10.1016/j.ssci.2006.08.024
11. Duarte J, Marques AT, Santos Baptista J. Occupational accidents related to heavy machinery: A systematic review. Safety. 2021; 7(1):21. https://doi.org/10.3390/safety7010021
12. Sanmiquel L, Rossell JM, Vintró C. Study of Spanish mining accidents using data mining techniques. Saf Sci. 2015; 75:49-55. https://doi.org/10.1016/j.ssci.2015.01.016
13. Ajith MM, Ghosh AK. Comparison of parameters for likelihood and severities of injuries in Artisanal and Small-scale Mining (ASM). Saf Sci. 2019; 118:212-220. https://doi.org/10.1016/j.ssci.2019.04.010
14. Ghosh AK, Bhattacherjee A, Chau N. Relationships of working conditions and individual characteristics to occupational injuries: a case-control study in coal miners. J Occup Health. 2004; 46(6):470-480. https://doi.org/10.1539/joh.46.470
15. Yi KH. The high-risk groups according to the trends and characteristics of fatal occupational injuries in Korean workers aged 50 years and above. Saf Health Work. 2018; 9(2):184-191. https://doi.org/10.1016/j.shaw.2018.01.005
16. Zhou X, Zhao X, Sun N, Wang D, Tong R. Establishing an index for monitoring occupational health and well-being of coal mines: Consideration of individual characteristics. Stress Health. 2023; 39(4):729-743. https://doi.org/10.1002/smi.3219
17. Gonzalez-Delgado M, Gómez-Dantés H, Fernández-Niño JA, Robles E, Borja VH, Aguilar M. Factors associated with fatal occupational accidents among Mexican workers: A national analysis. PLoS One. 2015; 10(3):e0121490. https://doi.org/10.1371/journal.pone.0121490
18. Barlas B, Izci FB. Individual and workplace factors related to fatal occupational accidents among shipyard workers in Turkey. Saf Sci. 2018; 101:173-179. https://doi.org/10.1016/j.ssci.2017.09.012
19. Agresti A. Categorical data analysis. John Wiley and Sons; 2012.
20. Schutte PC. Fatigue risk management: charting a path to a safer workplace. S Afr Inst Min Metall. 2010; 110(1):53-55.
21. Li B, Wang E, Shang Z, Xu G, Ali M, Wang H, Wu Q, Niu Y. Quantification study of working fatigue state affected by coal mine noise exposure based on fuzzy comprehensive evaluation. Saf Sci. 2022; 146:105577. https://doi.org/10.1016/j.ssci.2021.105577
22. Pelders J, Nelson G. Contributors to fatigue of mine workers in the South African gold and platinum sector. Saf Health Work. 2019; 10(2):188-195. https://doi.org/10.1016/j.shaw.2018.12.002
23. Pelders J, Magweregwede F, Rupprecht SM. Optimization of shift cycles in the South African mining sector. S Afr Inst Min Metall. 2021; 121(8):427-436. https://doi.org/10.17159/2411-9717/1428/2021
24. Stojadinović S, Svrkota I, Petrović D, Denić M, Pantović R, Milić V. Mining injuries in Serbian underground coal mines-A 10-year study. Injury. 2012; 43(12):2001-2005. https://doi.org/10.1016/j.injury.2011.08.018
25. Lerman SE, Eskin E, Flower DJ, George EC, Gerson B, Hartenbaum N, Hursh SR, Moore- Ede M. Fatigue risk management in the workplace. JOEM. 2012; 54(2):231-258. https://doi.org/10.1097/JOM.0b013e318247a3b0