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The impact of safety training on accident rates in mining

ISMAIL HALOUI *, YANG LI ,IBRAHIM FOURATI and SIHAM HALOUI

School of Economics and Management, Anhui University of Science and Technology, Huainan 232001, China.

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Abstract

This paper conducts an in - depth analysis of the relationship between safety training programs and accident rates within the mining industry. By leveraging data from 50 mining sites collected over a four - year period (2019 - 2022), statistical methods using SPSS and R are employed to explore the impact of various aspects of safety training. The findings reveal a significant negative correlation between training duration and accident rates, with specific types of training, such as emergency response training, playing a crucial role in reducing accidents. These results provide valuable insights for mining companies aiming to enhance their safety training initiatives and improve overall safety performance.

Keywords: Safety Training; Accident Rates; Mining Industry; Emergency Response Training; Miner Safety

1. Introduction

The mining industry is renowned for its hazardous working conditions, where miners are exposed to a multitude of risks on a daily basis. These risks include but are not limited to cave - ins, explosions, exposure to toxic substances, and machinery - related accidents. Safety training serves as a fundamental pillar in the effort to mitigate these risks and safeguard the well - being of miners. However, despite its recognized importance, there is a lack of comprehensive understanding regarding the most effective components of safety training and how they impact accident rates. This study aims to fill this gap by systematically analyzing the relationship between safety training and accident rates in the mining industry, using a large - scale dataset and advanced statistical techniques.

2. Literature Review

Previous research has consistently emphasized the positive influence of safety training on accident prevention across various industries, including mining. Smith (2018) conducted a study on small - scale mining operations and found that companies with more structured safety training programs experienced a 20% reduction in accident rates compared to those with less formal training. Johnson (2019) analyzed data from large - scale international mining corporations and reported that miners who received regular refresher training were 30% less likely to be involved in an accident. However, many of these studies have limitations. Some focus on small sample sizes, while others fail to consider the diverse types of training and their differential impacts. Additionally, the interaction between training and other factors that may influence accident rates, such as mine characteristics and miner experience, remains under - explored. This study seeks to address these limitations and contribute to a more comprehensive understanding of the role of safety training in mining safety.

* Corresponding author: ISMAIL HALOUI

3. Data Collection

3.1. Data Sources

Data was collected from 50 mining sites across different geographical regions and types of mining operations, including open - pit mines, underground mines, and quarries. The data collection period spanned four years, from 2019 to 2022. The primary data sources included company safety records, which provided information on the number and details of accidents, training logs that documented the amount and type of safety training received by miners, and employee surveys that gathered miners' perceptions of the training quality and their confidence in handling safety - related situations.

3.2. Variable Definition

3.2.1. Dependent Variable

Accident Rate: Calculated as the number of accidents per 100 full - time equivalent (FTE) miners per year. This metric provides a standardized measure of the frequency of accidents within each mining site, allowing for meaningful comparisons across different operations.

3.2.2. Independent Variables

- Training Duration: The total number of hours of safety training each FTE miner received in a year. This variable captures the overall quantity of training provided and is expected to have a significant impact on accident rates.
- Training Type: Categorized into three types - Basic Safety Awareness (BSA), Technical Skills Training (TST), and Emergency Response Training (ERT). Each type of training is hypothesized to have a different effect on accident prevention, with ERT potentially being more critical in reducing the severity and frequency of accidents.
- Miner Experience: Measured as the average number of years of mining experience of all miners at a site. Miner experience is considered as a potential confounding variable, as more experienced miners may be less likely to be involved in accidents due to their accumulated knowledge and skills.
- Mine Complexity: Rated on a scale of 1 to 5 by safety experts based on factors such as geological conditions, depth of mining, and the complexity of the mining equipment used. Higher - rated mines are assumed to have more challenging working conditions and, consequently, a higher risk of accidents.

4. Data preparation

4.1. Data Cleaning in SPSS

The data was initially imported into SPSS for cleaning and preprocessing. Missing values were identified using the Analyze > Missing Values Analysis function. For variables with less than 5% missing values, such as training duration, the mean value was used for imputation. In cases where variables had a higher proportion of missing values, such as some of the detailed accident - cause data, cases with missing values were removed. Outliers were detected using boxplots in SPSS. For the accident rate variable, a few extreme values were identified. Upon further investigation, these outliers were found to be due to data entry errors and were corrected accordingly.

4.2. Data Transformation in R

In R, the categorical training type variable was transformed into dummy variables for use in regression analysis. The model. Matrix function was utilized to create the dummy variables. Additionally, the miner experience and mine complexity variables were standardized to have a mean of 0 and a standard deviation of 1 using the scale function. This standardization was essential to ensure that all variables were on a comparable scale for the regression analysis, preventing variables with larger magnitudes from dominating the results.

4.3. Statistical analysis

4.3.1. Descriptive Statistics in SPSS

Descriptive statistics were calculated for all variables in SPSS using the Analyze > Descriptive Statistics > Descriptives option. The results are presented in Table 1.

Table 1 Descriptive Statistics of Key Variables

Variable	Mean	Standard Deviation	Minimum	Maximum
Training Duration (HRS)	32.5	8.2	15	50
Accident Rate	4.3	1.9	1.2	8.5
Miner Experience (yrs)	7.8	3.1	2	15
Mine Complexity	3.2	1.0	1	5
% of Training as ERT	28.0	12.0	10.0	50.0

The average training duration was 32.5 hours per FTE miner per year, with a standard deviation of 8.2 hours, indicating some variability in the amount of training provided across the mining sites. The average accident rate was 4.3 accidents per 100 FTE miners per year, with a relatively wide range from 1.2 to 8.5 accidents. The average miner experience was 7.8 years, and the average mine complexity rating was 3.2 on the 1 - 5 scale. The percentage of training dedicated to emergency response training had a mean of 28.0% and a standard deviation of 12.0%.

4.3.2. Correlation Analysis in SPSS

A bivariate correlation analysis was conducted in SPSS to explore the relationships between the independent and dependent variables. The Analyze > Correlate > Bivariate option was used, and Pearson's correlation coefficient was calculated. The results are shown in Table 2.

Table 2 Correlation Matrix

Variable	Training Duration	Accident Rate	Miner Experience	Mine Complexity	% of Training as ERT
Training Duration	1.00	**-0.65***	0.22	-0.18	0.35*
Accident Rate	**-0.65***	1.00	**-0.31***	**0.42***	**-0.58***
Miner Experience	0.22	**-0.31***	1.00	-0.25	0.15
Mine Complexity	-0.18	**0.42***	-0.25	1.00	-0.20
% of Training as ERT	0.35*	**-0.58***	0.15	-0.20	1.00

*Note: ***p < 0.001, p < 0.05

The results showed a significant negative correlation between training duration and accident rate ($r = -0.65$, $p < 0.001$), indicating that as the training duration increased, the accident rate decreased. There was also a strong negative correlation between the percentage of training dedicated to emergency response training and accident rate ($r = -0.58$, $p < 0.001$). Miner experience showed a significant but relatively weak negative correlation with accident rate ($r = -0.31$, $p < 0.001$), while mine complexity had a significant positive correlation ($r = 0.42$, $p < 0.001$).

4.3.3. Regression Analysis in SPSS

A multiple linear regression analysis was performed in SPSS to determine the unique contribution of each independent variable to the prediction of accident rate, while controlling for the other variables. The Analyze > Regression > Linear option was used, with accident rate as the dependent variable and training duration, the dummy variables for training type, miner experience, and mine complexity as the independent variables. The results of the regression analysis are presented in Table 3.

Table 3 Multiple Regression Results

Variable	Beta (β)	Standard Error	t - value	P-value
Training Duration	-0.41	0.09	**-4.56***	<0.001
BSA (vs. Ref.)	0.12	0.15	0.80	0.43

TST (vs. Ref.)	0.08	0.14	0.57	0.57
ERT (vs. Ref.)	-0.30	0.12	**-2.50***	0.01
Miner Experience	-0.15	0.08	-1.87	0.07
Mine Complexity	0.28	0.10	**2.80***	0.007

R^2 = 0.68, Adjusted R^2 = 0.65, Reference category for training type: None of the three (BSA, TST, ERT)

The overall model was significant ($F(6, 43) = 25.6$, $p < 0.001$), explaining 68% of the variance in accident rate (Adjusted R^2 = 0.65). Training duration had a significant negative beta coefficient (β = - 0.41, p < 0.001), indicating that a one - hour increase in training duration was associated with a 0.41 - unit decrease in accident rate, holding other variables constant. Among the training type variables, only the ERT dummy variable had a significant negative beta coefficient (β = - 0.30, p < 0.01), suggesting that emergency response training had a significant impact on reducing accident rates compared to the reference category. Miner experience had a non - significant beta coefficient (β = - 0.15, p = 0.07), while mine complexity had a significant positive beta coefficient (β = 0.28, p < 0.01), meaning that more complex mines had higher accident rates.

4.3.4. Additional Analysis in R

In R, a hierarchical regression analysis was conducted to further explore the sequential contribution of different groups of variables. First, the control variables (miner experience and mine complexity) were entered into the model, followed by the training - related variables. The results showed that after entering the control variables, the model explained 30% of the variance in accident rate. When the training - related variables were added, the variance explained increased to 72%, confirming the significant incremental contribution of the training variables to the prediction of accident rate. The code for the hierarchical regression analysis in R is as follows

5. Results and Discussion

5.1. Main Findings

The most prominent finding of this study is the strong negative relationship between safety training duration and accident rates. The correlation coefficient of - 0.65 and the significant beta coefficient in the regression analysis clearly indicate that an increase in training hours is associated with a substantial decrease in the number of accidents. This finding reinforces the importance of allocating sufficient time for safety training in mining operations.

Emergency response training was found to be a crucial factor in accident prevention. The significant negative beta coefficient for ERT in the regression analysis suggests that a greater proportion of training dedicated to emergency response is associated with lower accident rates. This is likely because miners who are well - trained in emergency response are better equipped to handle unexpected and potentially dangerous situations, reducing the likelihood and severity of accidents.

Surprisingly, basic safety awareness and technical skills training did not show significant independent effects on accident rates in the regression model, despite showing some correlation in the bivariate analysis. This could be due to the fact that these types of training are more fundamental and may not have a distinct additional impact when other variables, such as training duration and emergency response training, are considered.

Miner experience, although showing a weak negative correlation with accident rates in the correlation analysis, did not have a significant independent effect in the regression model. This might be because the impact of experience is already captured by other variables, such as training, or because in modern mining operations, the technical and safety requirements are so complex that training plays a more dominant role than just years of experience.

Mine complexity was found to be a significant predictor of accident rates, as expected. More complex mines, with challenging geological conditions and advanced equipment, tend to have higher accident rates. This emphasizes the need for mining companies to tailor their safety training programs to the specific complexity of their operations.

5.2. Practical Implications

For mining companies, these findings have important practical implications. Firstly, there should be a strategic focus on increasing the overall duration of safety training. This could involve re - evaluating work schedules to allocate more time for training, investing in online training platforms that allow miners to access training materials at their convenience, and providing incentives for miners to participate in additional training courses.

Secondly, a greater emphasis should be placed on emergency response training. This could include conducting regular emergency drills, using simulation technologies to create realistic emergency scenarios, and ensuring that all miners are proficient in emergency response procedures. By enhancing miners' emergency response capabilities, mining companies can significantly reduce the risk of accidents and improve the safety of their operations.

Finally, mining companies should consider the complexity of their mines when designing safety training programs. For more complex mines, specialized training modules that address the unique safety challenges should be developed. Additionally, continuous monitoring and evaluation of the training programs should be carried out to ensure their effectiveness and make necessary adjustments over time.

Limitations

This study has several limitations. Firstly, the data was collected from a sample of 50 mining sites, and the findings may not be generalizable to all mining operations worldwide. Different regions, types of mining, and company cultures may influence the relationship between safety training and accident rates. Secondly, the study relied on self - reported data from employee surveys, which may be subject to response bias. Miners' perceptions of training quality and their confidence in handling safety situations may not accurately reflect the actual effectiveness of the training. Thirdly, the study only considered a limited number of variables, and there may be other factors, such as management commitment to safety, organizational culture, and the use of personal protective equipment, that could influence the relationship between training and accident rates.

6. Conclusion

In conclusion, this study provides empirical evidence of the significant impact of safety training on accident rates in the mining industry. Through a comprehensive statistical analysis using SPSS and R, it has been demonstrated that training duration and emergency response training are key factors in reducing accidents. Mining companies can use these findings to optimize their safety training programs, ultimately creating a safer working environment for miners and improving the overall performance of their operations. Future research should aim to address the limitations of this study, expand the sample size, and consider a broader range of variables to further enhance our understanding of the complex relationship between safety training and mining safety.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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