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Innovative approaches to reducing workplace accidents in coal mining: Evidence from PMDN IUP companies in South Sumatra

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A B S T R A C T

This study examines the influence of the implementation of the Mining Safety Management System (SMKP) on workplace accident rates within coal mining operations. A quantitative research design was adopted, utilizing survey data obtained from 390 employees working in mining companies operating under IUP PMDN in South Sumatra. The variables investigated consist of technical risk control, adherence to Standard Operating Procedures (SOP), safety training and emergency drills, and the utilization of Personal Protective Equipment (PPE). Data analysis was conducted using multiple linear regression to assess both the individual (partial) and combined (simultaneous) effects of the independent variables on accident rates. The findings indicate that the regression model is statistically significant, with a coefficient of determination (R^2) of 0.436, suggesting that 43.6% of the variability in workplace accidents is explained by the variables included in the model. At the individual level, safety training and PPE utilization demonstrate a significant effect on accident rates, whereas technical risk control and SOP compliance do not exhibit a statistically significant influence. These results suggest that behavioral aspects have a more prominent role compared to system-related factors in mitigating workplace accidents. Accordingly, this study underscores the need to prioritize the enhancement of safety training programs, strengthen safety awareness, and ensure consistent PPE compliance as critical strategies for improving safety performance in the mining industry.

INTRODUCTION

The coal mining industry is widely regarded as one of the most high-risk sectors due to the complexity of its operations, the extensive use of heavy machinery, and the constantly changing working conditions that expose workers to significant hazards. These risks may arise from geotechnical instability, unsafe interactions between personnel and equipment, and inadequate adherence to established safety procedures. For this reason, the implementation of a robust occupational safety management system is essential to ensure operational continuity while safeguarding workers from potential harm (Ghahramani, 2016).

In Indonesia, occupational safety in the mining sector is governed by the Mining Safety Management System (Sistem Manajemen Keselamatan Pertambangan/SMKP), which is structured around a continuous improvement cycle encompassing planning, implementation, evaluation, and corrective action. However, existing studies suggest that the presence of a formal safety management system does not automatically lead to a reduction in workplace accidents, particularly when its application at the operational level is not carried out effectively (Abd Karim & Sejati, 2021). This condition reflects an ongoing disconnect between regulatory requirements and actual safety practices in the field.

More recently, the focus of occupational safety management has evolved from a purely compliance-based approach toward one that emphasizes behavioral aspects and practical implementation. The concept of Behavior-Based Safety (BBS) highlights the importance of individual actions in fostering a safer work environment through heightened awareness, proactive behavior, and the development of a strong safety culture within organizations (Carra et al., 2024). This perspective implies that safety outcomes are influenced not only by the existence of formal procedures but also by the consistency with which they are applied in daily operations.

Several factors have been identified as critical in mitigating workplace accidents, particularly in high-risk industries such as mining. Safety training has been shown to enhance workers' knowledge, improve hazard identification, and strengthen their ability to manage risks, thereby contributing to lower accident rates (Namian et al., 2016). Similarly, the consistent and proper use of personal protective equipment (PPE) plays a vital role in reducing the severity of injuries and limiting exposure to hazardous conditions (He et al., 2020). In contrast, factors such as compliance with Standard Operating Procedures (SOP) and technical risk control measures often demonstrate variable or indirect effects, as their effectiveness largely depends on enforcement mechanisms and the degree of behavioral compliance in real-world operations (Alruqi & Hallowell, 2019).

Empirical evidence further indicates that technical systems and procedural controls alone are insufficient to ensure optimal safety performance unless they are supported by effective supervision, clear communication, and active worker participation (Kines et al., 2010; Dyreborg et al., 2022). This suggests that many safety failures are not primarily caused by the absence of systems, but rather by weaknesses in their implementation, monitoring, and adherence at the operational level.

Based on these considerations, there is a clear need for a comprehensive analysis that examines the key determinants of workplace accident reduction, particularly within domestic mining companies (IUP PMDN) operating in South Sumatra. This study develops an analytical framework incorporating technical risk control, compliance with SOP, safety training and drills, and PPE utilization to evaluate their respective contributions to workplace accident rates.

Accordingly, this research is expected to contribute to the advancement of occupational safety knowledge in the mining sector while also offering practical guidance for mining companies in developing more effective, behavior-oriented safety strategies aimed at reducing accident rates and improving overall safety performance.

METHODS

This study adopts a quantitative research approach utilizing a cross-sectional survey design to investigate the relationship between the implementation of technical components of the Mining Safety Management System (SMKP) and workplace accident rates. Quantitative approaches are commonly applied in occupational safety studies to examine causal linkages between safety-related factors and accident outcomes (Hair et al., 2019). The cross-sectional design facilitates data collection at a single point in time, allowing for the identification of trends and associations among variables within the context of mining operations (Setia, 2016).

The research model comprises one dependent variable and four independent variables:

1. Dependent Variable (Y):
   Workplace accident rate
2. Independent Variables (X):
   a. Technical risk control
   b. Compliance with Standard Operating Procedures (SOP)
   c. Safety training and drills
   d. Use of Personal Protective Equipment (PPE)

Each variable is measured using structured indicators adapted from previous occupational safety studies and standardized safety management frameworks (Guo et al., 2016). The operationalization of these variables follows a Likert-scale measurement (1–5), which is commonly used to quantify perceptions and behaviors related to safety performance (Joshi et al., 2015).

The population of this study consists of workers in coal mining companies operating under IUP PMDN in South Sumatra. A total of 390 respondents were selected using a purposive sampling technique, which is appropriate when selecting respondents who have direct involvement in operational mining activities and safety practices (Etikan et al., 2016).

The sample size meets the recommended threshold for multivariate statistical analysis, where a minimum of 5–10 observations per variable is considered adequate (Hair et al., 2019).

Data were collected through two primary methods:

1. Questionnaire Survey

Structured questionnaires were distributed to respondents to measure perceptions and practices related to SMKP implementation. Questionnaires are widely used in safety research due to their efficiency in collecting standardized data from large samples (Rowley, 2014).

2. Field Observation

Direct field observations were conducted to identify non-conformities in safety implementation, including equipment inspection practices, dust control, slope stability monitoring, and PPE usage. Observational methods are essential to validate self-reported data and capture actual safety practices in high-risk environments (Lingard et al., 2010; Ozobu et al., 2023).

The collected data were processed and analyzed using the Statistical Package for the Social Sciences (SPSS) following a series of systematic analytical procedures:

1. Descriptive Statistics

Descriptive analysis was used to summarize the characteristics of the data, including mean, standard deviation, minimum, and maximum values. This method provides an overview of the distribution and central tendency of each variable (Field, 2024).

2. Validity and Reliability Tests
   a. Validity Test: Pearson correlation was used to assess the validity of each questionnaire item.
   b. Reliability Test: Cronbach's Alpha was applied to evaluate the internal consistency of the variables.

A Cronbach's Alpha coefficient greater than 0.6 is generally regarded as an acceptable threshold for internal consistency, indicating that the measurement instrument is sufficiently reliable (Taber, 2018).

To ensure the validity of the regression model, a series of classical assumption tests were conducted prior to the main analysis. The normality of the data distribution was evaluated using the Kolmogorov–Smirnov test complemented by the Monte Carlo approach. Multicollinearity was assessed through the examination of the Variance Inflation Factor (VIF) and tolerance values to ensure that the independent variables were not highly correlated. In addition, heteroscedasticity was tested using the Glejser method to verify the homogeneity of variance across observations. The presence of autocorrelation was examined using the Durbin–Watson statistic. These diagnostic procedures are essential to confirm that the fundamental assumptions of regression analysis are met, thereby ensuring the robustness and reliability of the estimated model (Hair et al., 2019).

Subsequently, multiple linear regression analysis was employed to examine the influence of the independent variables on workplace accident rates. This analytical method is widely applied to evaluate the extent to which several predictor variables simultaneously explain variations in a dependent variable, as well as to determine their individual contributions (Montgomery et al., 2021). The regression model is expressed as:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + \epsilon$$

Where:

Y= Workplace accident rate

X_1= Technical risk control

X_2= SOP compliance

X_3= Safety training and drills

X_4= PPE usage

a= Constant

b= Regression coefficients

3. Hypothesis Testing
   a. t-test: To evaluate the partial effect of each independent variable
   b. F-test: To assess the simultaneous effect of all independent variables
   c. Coefficient of Determination (R^2): To measure the explanatory power of the model

RESULTS AND DISCUSSION

This analysis is intended to assess the influence of the implementation of the Mining Safety Management System (SMKP) on workplace accident rates by considering both system-oriented and behavioral dimensions. The discussion is organized to provide a comprehensive interpretation of the findings, beginning with the validation of the statistical model, followed by an examination of the effect of each variable, and concluding with an integrated analysis of the role of safety-related behavior in reducing accident occurrences.

By integrating empirical results with established theoretical perspectives, this study aims to address the gap between formal system compliance and actual safety practices in the field, thereby offering valuable contributions to both the advancement of academic knowledge and the practical improvement of safety management in the mining sector.

Statistical Analysis and Model Validation

The descriptive statistical results show that all variables were derived from 390 valid responses, with no missing data identified. The mean scores for technical risk control, compliance with Standard Operating Procedures (SOP), safety training and drills, and the use of personal protective equipment (PPE) are generally within the moderate to high range, indicating that safety management practices have been formally established within the observed mining operations.

Nevertheless, the average level of workplace accidents remains relatively moderate, with a mean value of approximately 15. This finding suggests that, despite the presence of formal safety systems, the risk of workplace accidents in the study area remains considerable (Table 1). This condition implies that although safety management systems have been established, their effectiveness in reducing workplace accidents has not been fully optimized. Similar findings have been reported in previous studies, which highlight that the existence of safety systems alone does not guarantee improved safety performance without effective implementation at the operational level (Li & Guldenmund, 2018).

Table 1. Descriptive Statistics of Variables

Variable	Mean	Std. Dev	Min	Max
Technical Risk Control	16,9	2,45	4	20
SOP Compliance	12,8	1,89	3	15
Safety Training & Drill	12,8	1,96	3	15
PPE Usage	13,1	1,87	3	15
Workplace Accidents	15	3,64	4	20

Recent literature indicates that safety performance in high-risk industries is closely associated with the capacity of management systems to adapt and support continuous improvement processes (Leveson, 2016). Furthermore, proactive approaches to hazard identification have been demonstrated to substantially lower the probability of accidents in mining operations (Manuele, 2008; Sanni-Anibire et al., 2020). The incorporation of human factors into safety management frameworks is also considered crucial for achieving effective accident prevention (Dekker, 2016).

In addition, strong leadership commitment has consistently been identified as a critical factor influencing safety performance within industrial settings (Clarke, 2013; Lee et al., 2024). The advancement of digital-based safety monitoring systems further contributes to improved hazard detection and enhances overall operational safety in contemporary mining practices (Badri et al., 2018).

Furthermore, the analysis of mining accident trends over the period 2020–2024 reveals a fluctuating pattern followed by a significant decline in the most recent year. This trend indicates that safety performance improvement requires time and continuous effort, aligning with the concept of safety maturity, which emphasizes gradual development through sustained implementation and organizational learning (Hollnagel, 2018). The decreasing trend in accident rates suggests that improvements in safety practices may begin to show measurable results after consistent application over time.

The results of the data quality assessment, as presented in Table 1, indicate that all measurement instruments meet the required standards of validity and reliability, with Cronbach's Alpha coefficients exceeding the minimum acceptable threshold of 0.6 across all variables.

Furthermore, the classical assumption tests confirm that the regression model fulfills the necessary statistical criteria. The data are normally distributed, no evidence of multicollinearity is observed (VIF < 10), heteroscedasticity is not detected (significance values above 0.05), and the Durbin–Watson statistic falls within the acceptable range, indicating the absence of autocorrelation. These findings suggest that the regression model is statistically sound and appropriate for subsequent analysis, consistent with established methodological standards in multivariate analysis (Hair et al., 2019).

Effect of SMKP Variables on Workplace Accidents

The results of the multiple linear regression analysis, as presented in Table 2, indicate that the model yields a coefficient of determination (R^2) of 0.436 (see Table 3). This value suggests that 43.6% of the variation in workplace accident rates can be explained by the independent variables, namely technical risk control, compliance with Standard Operating Procedures (SOP), safety training and drills, and the use of personal protective equipment (PPE), while the remaining 56.4% is attributable to factors not included in the model. These findings imply that workplace accidents are shaped by a range of interrelated dimensions, including organizational, environmental, and behavioral factors, which aligns with previous research highlighting the multifaceted nature of safety performance in high-risk industries (Guo et al., 2016).

Furthermore, the results of the F-test, as shown in Table 4, demonstrate that all independent variables collectively exert a statistically significant effect on workplace accident rates. This confirms that the safety management system, when considered as an integrated framework, plays a crucial role in mitigating accident risks.

Table 2. Multiple Linear Regression Results

Variable	B	Std. Error	Beta	t-value	Sig.
(Constant)	-2,998	1,079	–	-2,778	0,006
Technical Risk Control	0,145	0,089	0,097	1,627	0,104
SOP Compliance	0,139	0,131	0,072	1,067	0,287
Safety Training	0,349	0,132	0,188	2,643	0,009
PPE Usage	0,712	0,129	0,365	5,508	0

Table 3. Model Summary

R	R Square	Adjusted R-Square	Std. Error
0,66	0,436	0,43	2,75

Table 4. ANOVA (F-Test Results)

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.253,09	4	563,272	74,473	0
Residual	2.911,91	385	7,563	–	–
Total	5.165,00	389	–	–	–

However, the results of the partial (t-test) analysis, as presented in Table 5, indicate that not all variables exert a statistically significant direct influence on workplace accident rates. Specifically, technical risk control and compliance with Standard Operating Procedures (SOP) do not show a significant effect. This finding suggests that the mere existence of formal safety systems and procedural frameworks does not automatically contribute to accident reduction, particularly when their implementation in practice is not carried out effectively. This finding supports the Swiss Cheese Model proposed by Reason (2016), which explains that accidents occur due to failures in multiple layers of defense, particularly at the implementation level. In many cases, safety procedures exist only as formal documentation without consistent enforcement in the field, leading to what is often referred to as a “compliance gap” (Kines et al., 2010; Dyreborg et al., 2022).

Table 5. Hypothesis Testing Summary

Hypothesis	Variable	Sig.	Decision
H1a	Technical Risk Control	0,104	Rejected
H1b	SOP Compliance	0,287	Rejected
H1c	Safety Training	0,009	Accepted
H1d	PPE Usage	0	Accepted

Behavior-Based Safety Perspective and Practical Implications

In contrast, safety training and drills are found to exert a statistically significant influence on workplace accident rates. This finding underscores the importance of enhancing workers' knowledge, awareness, and practical skills in hazard identification and risk response. From a theoretical standpoint, this result aligns with Human Capital Theory, which posits that training contributes to improved individual competence and performance (Burke et al., 2006; Gong et al., 2024). Empirical evidence further supports this relationship, demonstrating that safety training enhances hazard recognition and reduces unsafe behavior, particularly in high-risk sectors such as mining (Namian et al., 2016).

The use of personal protective equipment (PPE) emerges as the most influential variable affecting workplace accidents, as indicated by its highest standardized coefficient among all predictors. This suggests that direct protective measures play a pivotal role in mitigating the consequences of workplace hazards. According to the Hierarchy of Controls framework, PPE functions as the final layer of protection when hazards cannot be fully eliminated or controlled through engineering or administrative measures (He et al., 2020). Although PPE does not eliminate hazards, it is highly effective in reducing the severity of injuries, thereby serving as a critical component of safety management in mining operations.

Moreover, safety outcomes are more strongly shaped by worker engagement and behavioral compliance than by the mere availability of safety systems (Hale et al., 2010; Sarvari et al., 2024). The concept of safety climate has been shown to significantly influence both safety-related behavior and accident rates (Neal & Griffin, 2006; Schneider et al., 2017). In addition, the effectiveness of safety interventions depends on consistent supervision and reinforcement mechanisms (Vinodkumar & Bhasi, 2010; Naji et al., 2021). Risk perception also plays a critical role in influencing workers' decision-making processes and safety behavior (Tixier et al., 2014). Consequently, integrated safety approaches that combine technical and behavioral elements are generally more effective in reducing workplace accidents (Choudhry, 2014).

Overall, the findings of this study indicate a shift in occupational safety management from a predominantly compliance-oriented approach toward a behavior-based perspective. In this context, behavioral factors—such as safety training and PPE utilization—demonstrate a stronger influence on accident reduction compared to system-based factors, including SOP compliance and technical risk control. This outcome is consistent with the principles of Behavior-Based Safety (BBS), which emphasize that safety performance is largely determined by individual behavior rather than the mere existence of formal safety systems (Carra et al., 2024). Furthermore, the findings support the concept of safety culture, highlighting the role of organizational values, attitudes, and practices in shaping safety outcomes (Zohar, 2003; Dyreborg et al., 2022).

Accordingly, this study offers important practical implications for mining companies. It suggests that safety strategies should not be limited to the development of formal systems and procedures but should also prioritize behavioral dimensions through continuous training, strict enforcement of PPE usage, and the cultivation of a strong safety culture. The integration of technical and behavioral approaches is therefore essential to establish a more effective and sustainable safety management system within the coal mining industry.

CONCLUSION

This study aims to analyze the effect of the implementation of technical aspects of the Mining Safety Management System (SMKP) on workplace accident rates in coal mining operations. The results show that, simultaneously, technical risk control, SOP compliance, safety training and drills, and PPE usage have a significant effect on workplace accidents. However, partially, not all variables contribute significantly.

Technical risk control and SOP compliance are found to have no significant direct effect on workplace accident rates, indicating that the existence of formal safety systems and procedures does not automatically lead to improved safety performance without effective implementation at the operational level. In contrast, safety training and drills, as well as PPE usage, have a significant influence on accident rates, with PPE usage emerging as the most dominant factor.

These findings highlight that behavioral factors play a more critical role than system-based factors in reducing workplace accidents. This suggests that the effectiveness of safety management in mining operations depends not only on the availability of systems and procedures but also on the level of worker awareness, discipline, and compliance in applying safety practices.

Therefore, mining companies are recommended to strengthen safety strategies by focusing on improving training quality, enhancing safety culture, and ensuring strict enforcement of PPE usage. The integration of technical safety systems with behavior-based approaches is essential to achieve a more effective and sustainable reduction in workplace accidents in the coal mining industry.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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