JURNAL ILMIAH EKONOMI MANAJEMEN DAN BISNIS
Volume 4 (1), 2026 : 01-09
E-ISSN: 2987-3843 P-ISSN: 2986-9919

Analysis of Human, Technical, and Environmental Factors: A Case Study of Fatal Incident Triggers Among Workers at PT Freeport Indonesia

Navisya Delia Putri 1[1*], Ahmad Mustofa 2[2]
[1-2] PSDKU Politeknik Negeri Malang Kabupaten Lumajang, Jawa Timur, Indonesia

Email: Email: : navisya.deliap@gmail.com1, ahmadmustofa@polinema.ac.id2
[*)] **Corresponding Author**

Received: 7 May 2025

Revised: 7 September 2025

Accepted: 1 December 2025

Published online:

Abstract

This study offers an original contribution by integrating a systematic perspective to identify multidimensional causes of fatal work accidents in the mining sector, particularly at PT. Freeport Indonesia. The objective of this research is to analyze the underlying factors contributing to fatal accidents by examining human, technical, and environmental dimensions. The study employs a Systematic Literature Review (SLR) method, synthesizing recent and relevant scholarly sources to provide a comprehensive understanding of accident causation. The empirical findings reveal that fatal incidents are not caused by a single factor but rather by an interaction of safety procedure violations by workers (human factors), failures in ventilation systems and the absence of adequate gas detection tools (technical factors), as well as hazardous geological conditions that facilitate the accumulation of toxic gases (environmental factors). These findings highlight the complexity of occupational safety risks in mining operations. The implications of this study emphasize the need for integrated safety management, including enhanced worker training, technological system improvements, proactive environmental risk mitigation, and the strengthening of organizational safety culture to prevent future accidents.

Keywords:

Systematic Literature Review; Human Factors; Technical Factors; Environmental Risk; Mining Safety

INTRODUCTION

The mining sector has long been recognized as one of the most significant contributors to global economic development, generating substantial revenues and supporting both industrial growth and community welfare. In many countries, including Indonesia, mining activities play a crucial role in driving regional and national economies through employment generation, infrastructure development, and investment expansion (Janjuhah, 2021). However, behind its economic contributions, the mining industry is also characterized by high levels of occupational risk, particularly in relation to work accidents that often result in severe injuries or fatalities. These risks highlight the ongoing challenge of ensuring occupational safety and health (OSH) within mining operations.

Data from the Indonesian Central Statistics Agency (Badan Pusat Statistik) reported 137 mining-related work accidents in 2021, indicating that safety performance in the mining sector remains a critical issue requiring continuous improvement. Such figures underscore the need for more effective safety management systems to prevent workplace accidents and minimize fatalities. In principle, the concept of zero accident represents an ideal condition in which no work-related injuries or illnesses occur due to hazardous conditions. However, achieving this condition remains challenging due to the complex interaction of multiple risk factors within mining environments (Aisah, 2023).

Existing literature suggests that work accidents are rarely caused by a single factor; rather, they result from a combination of human, technical, and environmental elements (Saefullah et al., 2023). Human factors relate to worker behavior, competence, and compliance with safety procedures. Technical factors involve equipment reliability, system design, and operational processes. Environmental factors include physical and geological conditions that may create hazardous situations. The interaction among these factors forms a complex risk system that significantly influences accident occurrence in high-risk industries such as mining .

Empirical evidence from international contexts further illustrates the severity of mining accidents. For instance, a study documented that between 2004 and 2009, approximately 822 fatalities occurred due to gas explosions in coal mines in China (Li Xian-gong, 2009). Similar incidents have also been reported in Indonesia. A notable case occurred at the Big Gossan underground mine operated by PT Freeport Indonesia, where a subcontractor worker died and two others were rescued after exposure to toxic gas. This incident led to the temporary closure of the mining site, reflecting the serious consequences of safety failures in mining operations (Antara News, 2017). These cases demonstrate that mining accidents are not isolated events but systemic issues requiring comprehensive analysis and intervention.

Despite the growing body of research on occupational safety in mining, there remains a significant research gap in understanding how human, technical, and environmental factors interact simultaneously to cause fatal accidents (Anggraini & Saefullah, 2025). Most previous studies tend to focus on single dimensions, such as human error or equipment failure, without adequately addressing the interconnected nature of these risk factors. Furthermore, many studies rely on case-specific analyses without synthesizing broader patterns that can inform preventive strategies across different mining contexts. This limitation creates a gap between theoretical safety frameworks and their practical application in real-world mining operations.

In addition, conventional safety approaches in the mining industry often emphasize compliance with regulations and technical standards, while underestimating the role of behavioral and environmental dynamics. As a result, safety management systems may fail to capture the complexity of risk interactions, leading to ineffective prevention measures. This gap highlights the need for a more integrative analytical approach that combines multiple perspectives to better understand the root causes of mining accidents.

The novelty of this study lies in its integrative approach, which combines human, technical, and environmental perspectives within a single analytical framework using a Systematic Literature Review (SLR) method. Unlike previous studies that focus on isolated factors, this research seeks to provide a holistic understanding of accident causation by synthesizing findings from various scholarly sources. This approach allows for the identification of patterns, relationships, and underlying mechanisms that contribute to fatal accidents in mining operations. By doing so, the study offers a more comprehensive and evidence-based perspective that can support the development of more effective safety strategies.

Furthermore, this research contributes to the field of occupational safety by emphasizing the importance of contextual and systemic analysis in high-risk industries. The integration of multiple risk dimensions provides a more realistic representation of workplace conditions, particularly in underground mining environments where hazards are often interconnected. This perspective is expected to enhance both theoretical understanding and practical implementation of safety management in the mining sector.

Based on the identified research gap and the proposed novelty, the objectives of this study are clearly defined. First, this study aims to identify and analyze the key factors contributing to fatal work accidents in coal mining, focusing on human, technical, and environmental dimensions. Second, it seeks to examine how these factors interact and influence accident occurrence, providing a more comprehensive understanding of risk dynamics. Third,

the study aims to generate practical insights and recommendations that can support the improvement of occupational safety and health practices in the mining industry.

In conclusion, this study is positioned within the broader academic debate on occupational safety in high-risk industries, particularly mining. By addressing the gap in integrative analysis and proposing a holistic framework, the research is expected to contribute both theoretically and practically to improving safety performance. Ultimately, enhancing the understanding of accident causation is essential not only for preventing future incidents but also for ensuring the sustainability and social responsibility of the mining industry.

METHODS

This study employs a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize existing research related to fatal occupational accidents in the mining industry, particularly within the context of PT Freeport Indonesia. The SLR method is selected due to its rigor in systematically collecting and analyzing scientific evidence, thereby ensuring the reliability and validity of research findings. This approach follows structured procedures as outlined by Latifah (2020), enabling the researcher to distinguish between subjective interpretations and objective empirical evidence.

The research process began with the formulation of research questions focusing on the key factors contributing to fatal mining accidents, specifically examining three main dimensions: human, technical, and environmental factors. These dimensions are widely recognized in occupational safety literature as critical determinants of workplace accidents. The primary research question guiding this study is: *What are the dominant factors contributing to fatal occupational accidents in mining operations, particularly in PT Freeport Indonesia?*

Data collection was conducted through a systematic search of academic databases, including Google Scholar, ScienceDirect, and other reputable sources. The inclusion criteria for selecting articles were: (1) published within the last 10–15 years, (2) peer-reviewed journal articles, (3) studies focusing on occupational safety in mining or similar high-risk industries, and (4) research explicitly discussing human, technical, or environmental risk factors. Articles that did not meet these criteria or lacked methodological clarity were excluded from the analysis (Ramdhan, 2021).

The selected literature was then screened and categorized based on relevance to the research variables. A total of relevant studies were analyzed to extract key findings, methodological approaches, and identified risk factors. The analysis process involved coding and thematic classification, where findings from different studies were grouped into the three main

categories: human factors (e.g., behavior, training, compliance), technical factors (e.g., equipment failure, safety systems), and environmental factors (e.g., geological conditions, ventilation, and hazardous gases).

To enhance analytical rigor, this study adopts a qualitative synthesis approach, comparing and contrasting findings across different studies to identify patterns, similarities, and inconsistencies. This comparative analysis allows for a deeper understanding of how various factors interact and contribute to fatal accidents in mining environments.

Furthermore, the study integrates case-based insights related to PT Freeport Indonesia to contextualize the findings within a real-world setting. Although the research relies primarily on secondary data, triangulation is achieved by combining multiple sources, including academic literature, industry reports, and documented accident cases. This ensures that the conclusions drawn are grounded in comprehensive and credible evidence.

Overall, the SLR method in this study serves as a robust analytical tool to systematically explore the underlying causes of fatal mining accidents and to provide a well-founded basis for recommendations aimed at improving occupational safety and health practices in the mining sector.

RESULT AND DISCUSSION

The main finding of this study indicates that the fatal accident involving Hendri Monardi, a subcontractor employee at PT Freeport Indonesia's Big Gossan underground mine, was caused by a multidimensional convergence of risk factors. The incident reflects a complex interaction between human, technical, and environmental elements, forming an interconnected "accident chain" that ultimately led to the fatal exposure to toxic gas. This result confirms that workplace accidents in high-risk industries such as mining are rarely caused by a single factor, but rather by the accumulation and interaction of multiple systemic failures.

From the human element, the findings suggest that non-compliance with safety procedures was a critical contributing factor. The victim was suspected of entering a hazardous mining area without verifying air safety conditions, a behavior frequently associated with mining accidents. Previous studies indicate that unsafe acts and procedural violations contribute to approximately 60% of workplace accidents in the mining sector. This aligns with the findings of Ruff et al. (2011);Sutariyono et al., 2020), who emphasized that lack of safety awareness, insufficient training, and risky behavior significantly increase accident probability. In the context of subcontractor workers, this issue becomes more critical, as they often receive less comprehensive safety training compared to permanent employees. The empirical evidence in this

study reinforces the argument that strengthening safety training and ensuring strict compliance with operational procedures are essential to minimizing human-related risks.

From the technical element, the failure of the ventilation system emerged as a major determinant of the incident. The concentration of carbon monoxide (CO) at the accident site reached approximately 1,500 ppm, far exceeding the safe threshold of 25 ppm. This indicates that the ventilation system was unable to effectively dilute and remove toxic gases from the underground environment. Furthermore, the absence of active gas detectors and early warning systems significantly worsened the situation, as workers were not alerted to the presence of hazardous gases before entering the area. This finding is consistent with the study by Jones et al. (2019), which highlights that inadequate equipment maintenance, poor system reliability, and the absence of safety monitoring technologies are key contributors to mining accidents. Similarly, Smith (2008) (Juhari & Zubair, 2022) argues that technical system failures, particularly in high-risk environments, can amplify the impact of human error and environmental hazards. Therefore, the empirical results confirm that robust and well-maintained technical systems are fundamental in preventing fatal incidents.

From the environmental element, the geological and physical characteristics of the underground mine played a significant role in triggering the accident. The Big Gossan mine, located at a depth of approximately 2,640 meters, presents a high-risk environment prone to the accumulation of toxic gases due to limited air circulation and confined spaces. Changes in air pressure and mining activities such as drilling are likely to have contributed to the release of toxic gases from rock formations. This condition is consistent with the findings of Groves et al. (2007) and Khanzode et al. (2011), who emphasize that environmental factors such as poor ventilation, unstable geological conditions, and hazardous atmospheric composition are critical determinants of mining accidents. The environmental vulnerability identified in this study further supports the argument that mining safety cannot be separated from environmental risk management.

The integration of these three elements—human, technical, and environmental—demonstrates the existence of a systemic accident mechanism, where failures in one component intensify the risks in others. The ventilation system failure allowed toxic gases to accumulate, the absence of detection systems prevented early warning, and unsafe human behavior led to direct exposure. This interconnected chain of events illustrates the concept proposed by Kecojevic and Radomsky (2004), which states that accidents in mining are the result of interacting risk factors rather than isolated incidents.

When compared with previous studies, the findings of this research are consistent with the broader theoretical framework of occupational safety in high-risk industries. Khanzode et al.

(2012) highlight that effective accident prevention requires an integrated approach that simultaneously addresses human behavior, technical systems, and environmental conditions. Similarly, recent studies emphasize that safety management systems must move beyond compliance-based approaches and adopt a more holistic risk management perspective. The results of this study contribute to this academic debate by providing empirical evidence from a real-world mining case, reinforcing the importance of a multidimensional safety framework.

In addition, the findings reveal that the absence of a strong **safety culture** further exacerbates the risk of accidents. A weak safety culture may lead to negligence, poor communication, and lack of coordination among workers and management. This is in line with Aisah (2023) (Abas et al., 2024), who argues that achieving zero accidents requires not only technical improvements but also behavioral transformation and organizational commitment to safety. Therefore, building a strong safety culture that prioritizes risk awareness, continuous training, and proactive safety measures is essential for preventing similar incidents in the future.

In conclusion, the empirical results demonstrate that fatal mining accidents are the outcome of complex and interconnected factors. The study confirms that effective accident prevention strategies must address the interaction between human, technical, and environmental elements, rather than treating them as separate issues. This integrative understanding provides a more comprehensive basis for improving occupational safety and health practices in the mining industry.

CONCLUSION

This study concludes that fatal workplace accidents in underground mining, particularly in the Big Gossan incident at PT Freeport Indonesia, are the result of an interconnected interaction between human, technical, and environmental factors. From the human perspective, non-compliance with safety procedures and inadequate training—especially among subcontractor workers—significantly increase the risk of accidents. From the technical aspect, the failure of the ventilation system and the absence of gas detection and early warning systems led to the accumulation of carbon monoxide at dangerous levels. Meanwhile, environmental conditions, including underground geological characteristics and pressure changes, contributed to the release and concentration of toxic gases, creating a highly hazardous working environment. These findings confirm that workplace accidents are not caused by a single factor but by a systemic failure across multiple dimensions.

In relation to the research objectives, this study successfully identifies and explains the key determinants of fatal mining accidents through a multidimensional framework. The findings provide theoretical implications by reinforcing the importance of integrating human, technical,

and environmental perspectives in occupational safety analysis. This study also highlights the need for further research on the interaction between these elements to develop more comprehensive safety models in high-risk industries.

From a practical and policy perspective, mining companies are strongly recommended to strengthen safety management systems through continuous training programs, particularly for subcontractor workers, and strict enforcement of safety procedures. In addition, companies must ensure the reliability and maintenance of critical equipment, including ventilation systems and gas detection technologies. Policymakers and industry stakeholders should also promote the development of adaptive safety regulations and foster a strong safety culture that prioritizes risk awareness and prevention. Such integrated efforts are essential to minimize accident risks and improve occupational safety and health performance in the mining sector.

REFERENCES

Abas, F., Nurhayati, N., Saefullah, A., Mulasih, S., & Tafsiruddin, M. (2024). Penyuluhan Keamanan Berkendara Di Jalan Bersama Forum Komunikasi Lalu Lintas Kota Tangerang Selatan. *Jurnal Pelayanan Hubungan Masyarakat*, *2*(1), 24–40. https://doi.org/10.59581/jphm-widyakarya.v2i1.2890

Aisah. (2023). Analisis Resiko Terkait Kecelakaan Kerja di Tambang Batubara . Jurnal Ilmiah Kesehatan Masyarakat.

Coleman, P., Martini, L., & Ruff, T. (2011). Cedera yang terkait dengan mesin pertambangan AS dan prioritas penelitian keselamatan. Jurnal Internasional Cedera dan Promosi Keselamatan, 18(1), 11-20.

Anggraini, N., & Saefullah, A. (2025). HR Management Challenges in Managing a Hybrid Working System. *JULIAN: Journal of Law Education and Legal Science*, *1*(1), 22–26. https://doi.org/10.5281/zenodo.17128288

Groves, W. A., Kecojevic, V. J., & Komljenovic, D. (2007). analisis cedera dan kematian yang mendukung pertambangan. Safety Research Journal, 38(4), 461-470.

Janjuhah, H. T. Underground Assessment, (2021). Mining Integrated Hazard Management, Environmental Monitoring, and Policy Control Sustainability, in Pakistan. 13505. Retrieved April 26, 2022

Juhari, A., & Zubair, Z. (2022). Peranan Gaya Kepemimpinan dan Budaya Organisasi Dalam Meningkatkan Semangat Kerja Karyawan Pada PT. Angkasa Pura Supports Head Office Kemayoran Jakarta Pusat. *Jurnal Ilmiah Wahana Pendidikan*, *8*(24), Article 24. https://doi.org/10.5281/zenodo.7495963

Jones, A. M., Kirchsteiger, C., & Svenssson, O. (2019). Best practices for mining safety: Occupational hazard management. Journal of Occupational Safety and Health, 17(2), 275-291.

Latifah, L. a. (2020). Systematic Literature Review (SLR): Kompetensi Sumber Daya Insani Bagi Perkembangan Perbankan Syariah Di Indonesia. Al Maal: Journal of Islamic Economics and Banking, 63--80.

Li Xian-gong, S. X.-f.-f. (2009). Fatal gas accident prevention in coal mine: a perspective from feedback management complexity. Procedia Earth and Planetary Science, 1673 1677. Retrieved April 26, 2022, from

Maiti, J., Khanzode, V. V., dan Ray, P. K. (2011). Cedera dan kecelakaan akibat kerja: Sebuah studi komprehensif. 49(5), Safety Science, 685-697.

Maiti, J., Khanzode, V. V., dan Ray, P. K. (2012). Cedera dan kecelakaan yang berhubungan dengan pekerjaan: Sebuah studi komprehensif. 1355-1367 dalam Safety Science, 50(5).

Radomsky, M., dan V. Kecojevic (2004). penyebab dan dampak kematian yang berhubungan dengan loader dan truk di tambang. 42(8), Ilmu Keselamatan, 809-825.

Supar, E. (2017, Oktober). Retrieved from Antara News.

Ramdhan, M. (2021). *Metode Penelitian*. books.google.com. https://books.google.com/books?hl=en&lr=&id=Ntw_EAAAQBAJ&oi=fnd&pg=PR1&dq=manajemen+operasi&ots=f2rL9NNs3z&sig=TvsJwhx4BGCW390r_nGgUAfTX4c

Saefullah, A., Gustiawan, W., Kuraesin, A. D., Rahmawati, Nurasiah, & Moeljono. (2023). HUMAN RESOURCE MANAGEMENT FUNCTIONS IN BUSINESS SUSTAINABILITY: (Frozen Food Business Case Study). *Upajiwa Dewantara : Jurnal Ekonomi, Bisnis Dan Manajemen Daulat Rakyat*, *7*(2), Article 2.

Sutariyono, S., Firdaus, A., Arda, D. P., Noor, M. A., Siregar, F., Tafsiruddin, M., Rahmi, C., Saputri, H., Tahang, M., Saefullah, A., Permatasari, D. I., & Misbah, I. (2020). Pemantapan Sumber Daya Manusia (SDM) dalam Peningkatan Kesejahteraan Masyarakat Pengelola Sampah di Pasar Ciputat. *Jurnal Pengabdian Masyarakat Nusantara*, *2*(2), Article 2. https://doi.org/10.57214/pengabmas.v2i2.519

Supar, E. (2017, Oktober). Retrieved from Antara News. https://www.antaranews.com/berita/659329/karyawan-subkontraktor-freeport-tewas-hirup-gas-beracun