Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 8, No.3, July 2026, pp. 02603022-01 ~ 02603022-15
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v8i3.2490

Design and Evaluation of Hazard Analysis Procedures in Mining Occupational Safety Programs

Azhari Alriza*, Ardhianiswari Diah Ekawati

Program Studi Magister Teknik Industri, Binus Graduate Program, Universitas Bina Nusantara, Jl. Kebon Jeruk Raya No. 27, Jakarta Barat 11530 Jakarta, Indonesia

*azhari.alriza@binus.ac.id, dhina@binus.ac.id

Abstract. Workplace accidents in the mining industry remain high, highlighting the need for systematic hazard analysis to strengthen Occupational Health and Safety (OHS) programs. This study aims to design and evaluate a Hazard Analysis Procedure (HAP) model for PT. XYZ. Using quantitative methods, the research applied the Fuzzy Delphi technique to validate OHS parameters and the Fuzzy Analytic Hierarchy Process (FAHP) to determine their relative weights. Data were obtained from ten certified OHS experts through structured questionnaires. Twenty-four indicators were identified, grouped into six main criteria: management leadership, worker participation, hazard identification and assessment, hazard prevention and control, program evaluation and improvement, and accident frequency. FAHP results showed that management commitment (0.092), hazard identification (0.088), and program evaluation (0.081) were the most influential indicators. A 95% threshold was proposed as the benchmark for successful HAP implementation. Findings provide practical recommendations and support continuous improvement of mining OHS management systems.

Keywords: Hazard analysis procedure, occupational safety and health, fuzzy delphi, fuzzy analytic hierarchy process (FAHP), parameter K3

(Received 2025-08-04, Revised 2025-09-18, Accepted 2026-05-05, Available Online by 2026-06-17)

1. Introduction

The mining industry, including oil and gas operations, is widely recognized as one of the most hazardous sectors due to the complexity of its processes, the involvement of heavy equipment, and the frequent exposure to toxic materials and high-risk environments [1–3]. Globally, mining accidents contribute significantly to occupational injuries and fatalities, particularly in developing countries where regulatory enforcement and safety management systems may be less robust [4–6]. The International Labour Organization (ILO) estimates that more than 2.3 million people die annually from work-related accidents or diseases, with mining consistently ranked among the highest-risk sectors. These challenges highlight the urgent need for systematic and adaptive hazard analysis as the cornerstone of Occupational Health and Safety (OHS) programs [7,8].

In Indonesia, the importance of OHS is stipulated in Law No. 1 of 1970 on Occupational Safety, which requires every employer to provide safe working conditions and reduce the likelihood of occupational accidents. Despite this legal framework, the mining sector continues to report a high number of incidents [9–11]. For example, at PT. XYZ, a large oil and gas company operating in Riau, data from 2022–2024 indicate a concerning upward trend in work accidents. Although the company has implemented various OHS programs such as Job Safety Analysis (JSA), Individual Hazard Assessment (IHA), and Permit to Work systems, accident statistics demonstrate that the measures have not been sufficiently effective in preventing fatalities, lost-time incidents, and near misses.

Table 1. Workplace accidents at PT. XYZ

No	Year	Fatality	LTI	RWC	MTC	First Aid	Near Miss	UA/UC
1	2022	0	0	2	4	2	67	11.766
2	2023	1	2	2	5	1	46	10.011
3	2024	0	3	3	0	3	46	18.896

Source: HES Department PT. XYZ (2024)

Note.
LTI : Lost Time Incident
RWC : Restricted Work Case
MTC : Medical Treatment Case
UA/UC : Unsafe Action/Unsafe Condition

The table above provides information on the number of workplace accidents each year, which has generally increased over the past three years. However, in subsequent years, it is clear that PT. XYZ has implemented an Occupational Safety and Health (K3) program. These recurring accidents not only result in human suffering and financial losses but also disrupt operations and undermine organizational reputation.

Hazard Analysis Procedures (HAP) are designed to identify, evaluate, and control potential risks associated with workplace activities [12–14]. In practice, hazard analysis frameworks such as Failure Mode and Effect Analysis (FMEA), Hazard and Operability Study (HAZOP), Bowtie analysis, and Job Hazard Analysis (JHA) have been widely applied in various industries. However, their effectiveness depends largely on systematic evaluation and integration into broader OHS management systems. International standards such as ISO 45001 and OSHA guidelines emphasize the importance of management leadership, worker participation, systematic hazard identification, preventive control measures, and continuous improvement in building a resilient OHS framework. Despite this, research in the Indonesian mining context has shown limited use of quantitative approaches that validate hazard parameters and prioritize risk factors systematically [15]. Previous studies tend to be descriptive, focusing on listing hazards without providing structured models or measurable indicators to evaluate the effectiveness of OHS programs [16].

A growing body of international literature has introduced quantitative and hybrid methods to strengthen hazard analysis and risk evaluation. For example, Unver & Ergenc (2021) applied the Analytic Hierarchy Process (AHP) to assess safety risks in forest logging, demonstrating the method's potential to prioritize risks systematically [17]. Nguyen et al. (2023) developed a Total Quality Management (TQM) 4.0 model using Delphi and AHP techniques, highlighting the role of management commitment and socio-technical integration in sustaining organizational performance [18]. Similarly, Sari & Ekawati (2025) employed Fuzzy Delphi and Fuzzy AHP to evaluate quality management in the cement industry, identifying 58 indicators that supported sustainable production [19]. These studies underscore the utility of combining expert judgment with quantitative models to provide structured, evidence-based insights into complex systems. However, the application of such models in mining OHS hazard analysis remains underexplored, particularly in Indonesia.

This research addresses that gap by integrating Fuzzy Delphi and Fuzzy Analytic Hierarchy Process (FAHP) to design and evaluate a hazard analysis procedure tailored for mining OHS programs. The Fuzzy Delphi method enables the systematic validation of hazard indicators by capturing expert consensus while managing uncertainty in expert opinions. Subsequently, FAHP is applied to assign relative weights to validated indicators, thereby prioritizing key aspects of hazard management. This dual approach offers a structured framework that enhances transparency and objectivity in hazard analysis, ensuring that decision-making is based on quantifiable evidence rather than purely descriptive assessments.

The purpose of this study is to design and evaluate the Hazard Analysis Procedure (HAP) model in the Occupational Safety and Health (OSH) program in the mining sector, particularly at PT. XYZ, using a quantitative approach through the Fuzzy Delphi and Fuzzy Analytic Hierarchy Process (FAHP) methods. This study aims to systematically validate OSH indicators based on expert consensus and determine their relative weights in order to prioritize the most influential aspects of hazard management. Through the resulting model, this study is expected to provide a measurable and transparent framework for identifying, evaluating, and controlling risks, as well as serving as a basis for companies to improve their OSH management systems, reduce workplace accidents, and support the implementation of international standards such as ISO 45001 and ILO principles.

2. Methods

2.1. Research Design

This study employed a quantitative-exploratory design using a hybrid approach that combined the Fuzzy Delphi Method (FDM) for validating hazard indicators and the Fuzzy Analytic Hierarchy Process (FAHP) for determining their relative weights. The methodological framework was developed to systematically evaluate the Hazard Analysis Procedure (HAP) implemented at PT. XYZ, a mining and oil company operating in Riau, Indonesia. The overall research process was conducted in three stages: (i) identification and validation of OHS indicators, (ii) weighting and prioritization of validated indicators, and (iii) model evaluation using dashboard simulation.

2.2. Research Location and Period

The study was conducted at B Field, PT. XYZ operational area. Data collection and analysis were carried out from 2023 to 2025, covering the stages of instrument development, expert consultation, data analysis, and reporting.

2.3. Participants

The study involved 10 certified OHS experts with recognized professional qualifications, including AK3U (General OHS Expertise) and AK3 Migas (Oil and Gas OHS Expertise). The experts were selected based on the following criteria:

1. Minimum of five years of professional experience in mining or oil and gas safety management.
2. Active involvement in hazard analysis or OHS program evaluation.
3. Willingness to participate voluntarily and provide informed consent.

The anonymity and confidentiality of responses were ensured throughout the research process.

2.4. Data Collection Procedures

A preliminary Delphi questionnaire was designed to collect expert opinions on the relevance of selected OHS indicators derived from literature reviews (ISO 45001, OSHA guidelines, EU-OSHA reports, and previous studies). Respondents were asked to assess whether each indicator was suitable for inclusion in the HAP evaluation model. Responses were recorded electronically and analyzed to refine the indicator list.

The refined indicators were further evaluated using the Fuzzy Delphi Method (FDM) with a 7-point Likert scale. Each expert assessed the importance of indicators, and triangular fuzzy numbers were used to manage uncertainty in expert judgments. Indicators with a consensus threshold above α-cut = 0.70 were retained for further analysis. This process reduced subjective bias and ensured systematic agreement among experts.

The validated indicators from Stage 2 were weighted using Fuzzy Analytic Hierarchy Process (FAHP). Experts were asked to perform pairwise comparisons on a 9-point Likert scale, enabling prioritization of indicators. Fuzzy pairwise matrices were aggregated and defuzzified using the extent analysis method. The final weights provided a quantitative ranking of indicators, highlighting the most influential factors for HAP effectiveness.

Dashboard Simulation

The weighted indicators were integrated into a dashboard model to visualize performance thresholds. A 95% benchmark was proposed as the threshold for successful HAP implementation. The dashboard displayed indicator performance levels using color-coded schemes (dark blue ≥95%, light blue <95%). This simulation allowed identification of weak indicators and supported decision-making for targeted improvements.

2.5. Instrument Development and Reliability

The research instrument consisted of structured questionnaires administered through Google Forms and electronic distribution (WhatsApp/email). To ensure reliability, the instrument underwent internal consistency testing using Cronbach's Alpha, with $\alpha \geq 0.70$ considered acceptable for exploratory research and $\alpha \geq 0.80$ recommended for applied research.

2.6. Data Analysis

Data analysis followed these steps:

1. Aggregation of expert judgments (Delphi → FDM → FAHP).
2. Defuzzification of fuzzy numbers to obtain crisp values.
3. Ranking of indicators based on FAHP weights.
4. Performance simulation through dashboard visualization.

Microsoft Excel was used for computational processing, while diagrams and charts were prepared to support analytical clarity.

2.7. Ethical Considerations

The study complied with ethical research standards. Participation was voluntary, informed consent was obtained, and responses were anonymized to protect expert confidentiality. No sensitive personal or company-specific data were disclosed beyond aggregated findings.

2.8. Research Framework

The overall methodological process can be illustrated as follows:

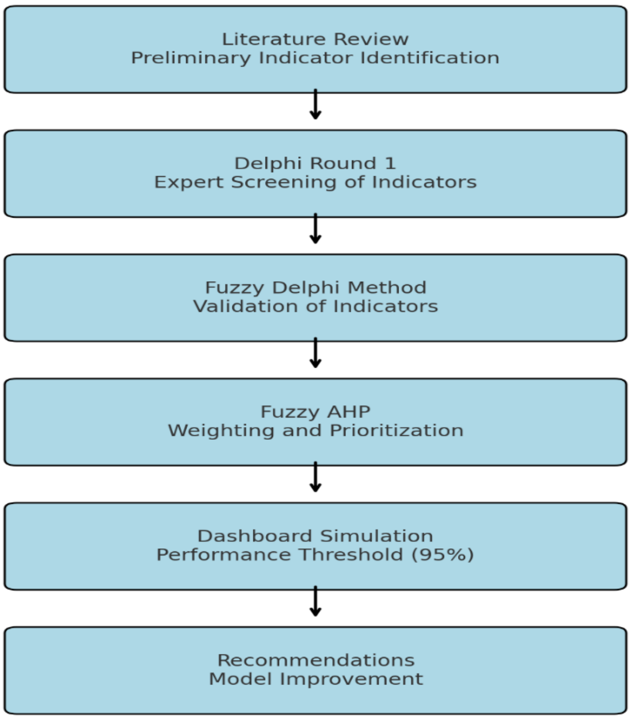

Figure 1. Research Methodology Framework

3. Results and Discussion

3.1. Results

Table 2. Hazard Indicators Validated through Fuzzy Delphi

Criteria	Indicators (Validated)	Consensus (%)
Management Leadership	Management Commitment, OHS Policy, Leadership Engagement, Budget Allocation, Top-Down Control	90–95%
Worker Participation	Training & Competence, OHS Communication, Worker Empowerment, Participation in Inspection	88–92%
Hazard Identification & Assessment	Risk Identification, Field Inspection, Risk-Based Checklist, Hazard Recording, Job Safety Analysis (JSA), Permit to Work	85–93%
Hazard Prevention & Control	PPE Usage, SOP Compliance, Engineering Controls, Preventive Maintenance, Emergency Response	87–94%
Program Evaluation & Improvement	OHS Performance Monitoring, Internal & External Audit, Continuous Improvement	89–91%
Accident Frequency	Near Miss Reporting, Lost Time Incident (LTI) Monitoring	86–90%

The Fuzzy Delphi analysis confirmed that out of the initial set of indicators, 24 were validated by experts with consensus levels exceeding 85%, ensuring their reliability as components of the HAP evaluation model. Among these, management leadership achieved the highest consensus (95%), highlighting the central role of leadership commitment as the foundation for effective OHS program implementation. Furthermore, the hazard identification category contained the largest number of indicators (six items), which reflects the strategic importance of systematic and comprehensive hazard detection processes in preventing workplace accidents and strengthening overall safety performance.

Table 3. Indicator Weights using Fuzzy AHP

Rank	Indicator	Weight (FAHP)	Category
1	Management Commitment	0.092	Management Leadership
2	Hazard Identification	0.088	Hazard Identification
3	OHS Program Evaluation	0.081	Program Evaluation
4	Worker Participation	0.078	Worker Participation
5	Hazard Prevention & Control	0.075	Hazard Prevention
6	Near Miss Reporting	0.071	Accident Frequency
7	Risk Communication	0.070	Worker Participation
8	OHS Inspection	0.069	Hazard Identification
9	Internal Audit (ISO 45001-based)	0.068	Program Evaluation
10	Performance Measurement & Monitoring	0.066	Program Evaluation
11–24	Remaining Indicators (e.g., PPE usage, SOP compliance, preventive maintenance, emergency response, permit to work, field checklist, empowerment programs, etc.)	0.060–0.065	Mixed Categories

The FAHP results demonstrated that the three top-ranked indicators—management commitment, hazard identification, and OHS program evaluation—consistently emerged as dominant factors in determining the effectiveness of the HAP model. In contrast, mid-level indicators such as near miss reporting, risk communication, inspections, internal audits, and performance monitoring emphasized the critical role of early detection mechanisms and continuous evaluation in sustaining safety performance. Meanwhile, other indicators including PPE usage, SOP compliance, preventive maintenance, emergency response, and permit to work had lower weights (0.060–0.065), indicating their supportive but necessary role in maintaining balance within the OHS framework. Overall, the distribution of weights confirms that leadership, hazard detection, and systematic evaluation form the core drivers of HAP effectiveness, while technical and administrative controls complement these pillars to create a comprehensive and resilient safety management system.

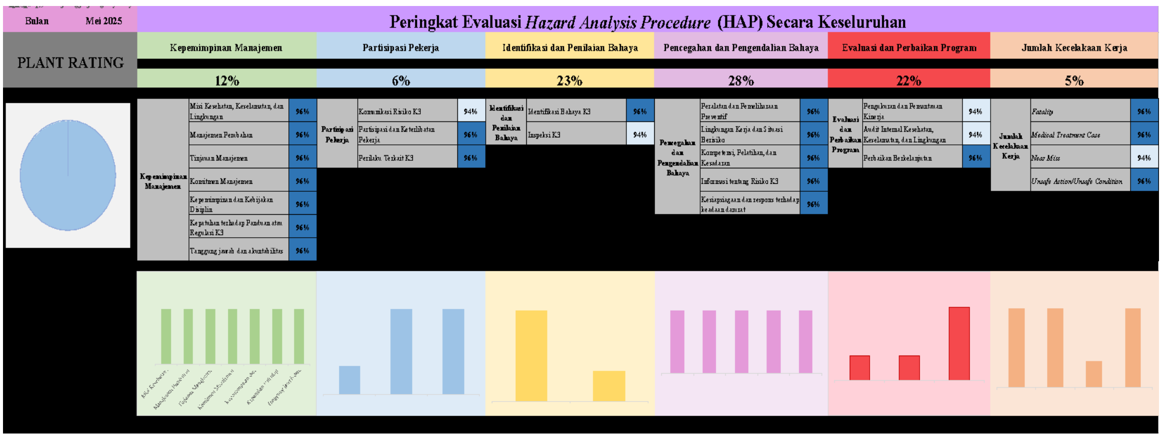

Figure 2. Display Dashboard from The HAP evaluation model

The dashboard simulation was developed to provide a visual representation of the performance of the Hazard Analysis Procedure (HAP) indicators at PT. XYZ. A success threshold of 95% was established, based on expert consensus, accident trends, and alignment with international standards such as ISO 45001, which emphasize continuous improvement and proactive hazard management. Indicators that reached or exceeded this threshold were displayed in dark blue, indicating satisfactory performance, while those below the threshold were shown in light blue, highlighting areas requiring immediate corrective action.

The simulation revealed that most indicators were close to the target, with an average performance of 94–96%. However, several critical indicators fell slightly below the benchmark, including OHS risk communication (94%), OHS inspection (94%), performance measurement and monitoring (94%), internal audit (94%), and near miss reporting (94%). Although the deviations appear marginal, their strategic importance cannot be underestimated. Weaknesses in communication, inspection, and monitoring reduce the organization's ability to detect hazards early and to implement timely interventions. Similarly, underperformance in internal auditing limits the capacity to ensure compliance with safety standards, while inadequate near miss reporting prevents the company from learning from early warning signals that often precede serious incidents.

On the other hand, indicators such as management commitment and hazard identification systems consistently performed above 95%, confirming that leadership support and systematic risk detection are already embedded in PT. XYZ's safety culture. The simulation also demonstrated that improvements in the underperforming indicators could create a cascading effect, strengthening the overall effectiveness of the HAP model and reducing accident frequency over time.

Overall, the dashboard serves not only as a monitoring tool but also as a decision-support system, enabling managers to prioritize resources and corrective actions toward indicators that are most vulnerable. This quantitative visualization underscores the practical value of the HAP evaluation model and aligns with international best practices that advocate for real-time performance measurement and continuous improvement in occupational health and safety management systems.

3.2 Discussion

The findings of this study highlight that management commitment, hazard identification, and program evaluation are the most influential indicators in determining the effectiveness of the Hazard Analysis Procedure (HAP) at PT. XYZ. The FAHP results demonstrated that these three factors carried the highest weights, underscoring their strategic role in shaping a safety culture and ensuring that hazards are systematically identified and controlled. This outcome is consistent with the accident data of PT. XYZ, which show that incidents continue to occur despite the presence of various OHS programs. The persistence of accidents indicates that technical measures alone are insufficient unless they are supported by strong leadership, systematic evaluation, and proactive worker engagement.

The dashboard simulation further reinforced these findings by showing that although most indicators approached the 95% performance threshold, several critical dimensions such as OHS communication, inspections, internal audits, performance monitoring, and near miss reporting remained below the target (94%). While the difference may appear marginal, these elements play a decisive role in early hazard detection and continuous improvement. For example, weak communication channels can hinder the dissemination of safety information, leading to misunderstandings and unsafe practices in the field. Similarly, inadequate near miss reporting limits organizational learning, as potential hazards are not documented and addressed before escalating into serious incidents. The identification of these gaps provides actionable insight for PT. XYZ, suggesting that attention should be redirected from solely technical compliance to strengthening organizational processes that sustain long-term safety performance.

The dominance of management commitment as the top indicator aligns with international standards such as ISO 45001, which places leadership engagement at the core of occupational health and safety management systems. Leadership commitment ensures the allocation of adequate resources, the enforcement of safety policies, and the establishment of accountability mechanisms. This result also resonates with the findings of [18], [20], and [21] who demonstrated that management support and quality culture were more critical than purely technical aspects in sustaining organizational performance under the TQM 4.0 framework.

The focus on hazard identification aligns with recent studies in various sectors, highlighting its central role in effective risk management. For instance, Zhao et al. (2023) applied a combined Fuzzy Analytic Hierarchy Process (FAHP) and Set Pair Analysis (SPA) to assess operational safety risks in long highway tunnels, demonstrating that integrating subjective expert judgments with objective evaluation improves assessment accuracy [22]. Similarly, Mohsen et al. (2021) employed a semiquantitative FAHP-based technique to evaluate construction project risks, assigning weighted contributions to factors of probability and severity, which helped prioritize preventive measures for occupational incidents [23]. In the environmental sector, Moloudi et al. (2022) used a hybrid Fine-Kinney, EFMEA, and AHP approach to identify and prioritize HSE hazards in solid waste management facilities, showing the method's reliability in focusing corrective actions on high-risk hazards [24].

The emphasize on program evaluation is supported by multiple studies across different industries, demonstrating its critical role in maintaining operational effectiveness and safety. For instance, Mousavi et al. (2023) applied Delphi and FAHP techniques to identify and prioritize factors affecting needlestick injuries, showing that systematic assessment of influencing factors guides targeted preventive measures [25]. In manual assembly, Alqahtani & Noman (2024) utilized Fuzzy Delphi and FAHP to rank human error factors, revealing that structured evaluation of individual, tool, and task-related factors enables organizations to implement effective error-reduction strategies [26]. Similarly, Ketsakorn & Kosolsaksakul (2025) employed Delphi and AHP to determine the importance of ISO 45001 requirements in small organizations, highlighting that prioritizing leadership, worker participation, and operational elements enhances occupational safety outcomes [27]. Collectively, these findings indicate that hybrid quantitative approaches such as Fuzzy Delphi, FAHP, and AHP provide a robust framework for program evaluation, allowing organizations across manufacturing, healthcare, and safety-critical industries to systematically identify, prioritize, and improve key operational processes.

The practical implications of these findings are significant for PT. XYZ and other companies operating in high-risk industries. First, the study underscores the necessity of strengthening worker participation through interactive and two-way communication. By ensuring that workers are actively involved in inspections and hazard reporting, companies can increase situational awareness and empower employees to become frontline contributors to safety culture.

Second, the findings point to the importance of risk-based inspections and performance monitoring. Rather than relying solely on compliance checklists, inspections should be designed to identify systemic weaknesses and to anticipate emerging risks. Integrating digital dashboards, as demonstrated in this study, provides managers with real-time visibility into OHS performance and facilitates evidence-based decision-making.

Third, the study highlights the need for robust auditing systems aligned with ISO 45001 standards. Independent and competent auditors are essential for ensuring compliance, identifying hidden risks, and maintaining organizational accountability. In addition, near miss reporting systems should be strengthened to encourage workers to document unsafe conditions without fear of reprisal. Such systems not only enhance hazard detection but also promote a culture of transparency and continuous learning.

Finally, the introduction of a 95% performance threshold represents an innovative benchmark that can be adopted by mining companies as a practical measure of HAP effectiveness. This threshold provides a quantifiable target that facilitates performance evaluation and drives continuous improvement, thereby aligning corporate practices with international best practices.

Despite its contributions, the study has several limitations. First, the sample size was relatively small, involving only 10 OHS experts from a single company. While the experts were certified and experienced, the limited sample restricts the generalizability of the findings. Future research should involve a larger and more diverse group of respondents, including practitioners from different mining companies and regulatory bodies.

Second, the study relied primarily on expert judgment rather than empirical accident data for weighting indicators. Although FAHP provides a robust framework for managing uncertainty, the absence of large-scale empirical validation means that the model's predictive power remains untested.

Combining expert judgment with statistical analysis of accident databases would strengthen the validity of the model.

Third, the study was conducted within the context of an Indonesian oil and gas company. Cultural, regulatory, and organizational factors may influence the applicability of the findings to other countries or industries. Comparative studies across different contexts would help to assess the model's adaptability and global relevance.

Future research should aim to expand the scope of the model by incorporating multi-criteria decision-making methods such as Bowtie analysis, Monte Carlo simulation, or Bayesian networks to validate and enhance risk predictions. In addition, the integration of big data analytics and digital monitoring systems could enable more dynamic hazard identification and predictive safety management. Cross-industry and cross-country collaborations would also provide opportunities to test the model's robustness and to identify universal versus context-specific indicators of HAP effectiveness. Finally, future studies should include longitudinal data to examine whether improvements in identified weak indicators (e.g., communication, inspection, near miss reporting) translate into measurable reductions in accident rates over time.

4. Conclusion

This study designed and evaluated a Hazard Analysis Procedure (HAP) model for mining occupational safety programs using Fuzzy Delphi and Fuzzy AHP, resulting in the validation of 24 OHS indicators across six criteria, with management commitment (0.092), hazard identification (0.088), and program evaluation (0.081) identified as the most influential. The dashboard simulation established a 95% performance threshold, revealing that while most indicators approached the target, weaknesses remained in communication, inspection, auditing, and near miss reporting. These findings underscore that leadership, systematic risk detection, and continuous evaluation are critical for effective hazard management, while active worker participation and robust monitoring systems strengthen organizational safety culture. Despite limitations related to sample size and reliance on expert judgment, the study contributes a hybrid quantitative framework and practical recommendations that can help mining companies reduce accidents, enhance compliance with ISO 45001 and ILO standards, and support continuous improvement in OHS performance.

Declaration of AI and AI assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT in order to assist with language refinement, grammar checking, sentence restructuring, and improving the clarity and readability of the manuscript. After using this tool/service, the author(s) carefully reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This section expresses its gratitude to those who have a role in conducting research activities, for example the laboratory where the research is conducted. The role of donors or those supporting research is briefly mentioned. Lecturers who are writers do not need to be listed here.

References

[1] Hao M, Nie Y. Hazard identification, risk assessment and management of industrial system: Process safety in mining industry. Saf Sci 2022;154:105863. https://doi.org/10.1016/j.ssci.2022.105863

[2] Rudakov M, Gridina E, Kretschmann J. Risk-based thinking as a basis for efficient occupational safety management in the mining industry. Sustainability 2021;13:470. https://doi.org/10.3390/su13020470

[3] Na XU, Ling MA, Li W. An improved text mining approach to extract safety risk factors from construction accident reports. Saf Sci 2021;138:105216. https://doi.org/10.1016/j.ssci.2021.105216

[4] Dodoo JE, Al-Samarraie H. A systematic review of factors leading to occupational injuries and fatalities. J Public Health (Bangkok) 2023;31:99–113.

[5] Debela MB, Azage M, Begosaw AM, Kabeta ND. Factors contributing to occupational injuries among workers in the construction, manufacturing, and mining industries in Africa. J Public Health Policy 2022;43:487–502.

[6] Samarasinghe H, Heenatigala S. Insights from the field: A comprehensive analysis of industrial accidents in plants and strategies for enhanced workplace safety. ArXiv Preprint ArXiv:240305539 2024. https://doi.org/10.4236/ojsst.2024.141001

[7] Cruz-Ausejo L, Cama-Ttito NA, Solano PF, Copez-Lonzoy A, Vera-Ponce VJ. Occupational accidents in mining workers: scoping review of studies published in the last 13 years. BMJ Open 2024;14:e080572. https://doi.org/10.1136/bmjopen-2023-080572

[8] ILO. EU-ILO Partnership: Safe and Healthy Workplaces for All. Https://WwwIloOrg/Publications/Eu-Ilo-Partnership-Safe-and-Healthy-Workplaces-All 2025.

[9] Iqbal M, Kamaludin A. Analisis faktor penyebab kecelakaan kerja pada pekerja pertambangan. Jurnal Keselamatan, Kesehatan Kerja Dan Lingkungan (JK3L) 2021;2.

[10] Rahmadani GF, Dwi Putri H, Irwansyah MI. Penerapan Kesehatan Dan Keselamatan Kerja (K3) Pada Pertambangan Mineral Dan Batubara. Research Gate, March 2021:1–3.

[11] Saputra FT, Arisanti R, Yansen D. Analisis Penerapan Kesehatan dan Keselamatan Kerja (K3) Pertambangan di PT Lematang Coal Lestari Gunung Raja Sumatera Selatan. Unpra Engineering Journal 2024;1:10–4.

[12] Agarwalla S, Singh SK, Ibrahim MA, Duraiswamy S. Safety Management: Hazard Identification and Risk Assessment at the Workplace. Chemical Engineering Essentials 2: Advanced Processes, Materials, and Sustainability 2025:247–76. https://doi.org/10.1002/9781394372379.ch11

[13] Baghaei Naeini SA, Badri A. Identification and categorization of hazards in the mining industry: A systematic review of the literature. International Review of Applied Sciences and Engineering 2024;15:1–19. https://doi.org/10.1556/1848.2023.00621

[14] Spanidis P-M, Roumpos C, Pavloudakis F. A fuzzy-AHP methodology for Planning the risk management of Natural hazards in surface mining projects. Sustainability 2021;13:2369. https://doi.org/10.3390/su13042369

[15] Punithan PE, Ramakrishnan R, Nallavan G, Jayanarasimhan K. Engineering Design and Prototyping of an Automated Shuttlecock Feeder with Programmable Court-Zone Targeting. International Journal of Environment, Engineering and Education n.d.;8:51–64. 10.55151/ijeedu.v8i1.335

[16] Andriani A, Istijono B, Alfito A, Akmal F, Adji BM. Identification of landslide hazard in residential area Kubang Tangah District, Sawahlunto. Journal of Applied Engineering and Technological Science (JAETS) 2024;5:1154–64. https://doi.org/10.37385/jaets.v5i2.3893

[17] Unver S, Ergenc I. Safety risk identification and prioritize of forest logging activities using analytic hierarchy process (AHP). Alexandria Engineering Journal 2021;60:1591–9. https://doi.org/10.1016/j.aej.2020.11.012

[18] Nguyen TA Van, Tucek D, Pham NT. Indicators for TQM 4.0 model: Delphi method and analytic hierarchy process (AHP) analysis. Total Quality Management & Business Excellence 2023;34:220–34. https://doi.org/10.1080/14783363.2022.2039062
[19] Purnama Sari AAMW, Ekawati AD. Developing a Product Quality Management Evaluation Model for a Sustainable Cement Industry in Indonesia. IOP Conf. Ser. Earth Environ. Sci., vol. 1488, IOP Publishing; 2025, p. 012012. 10.1088/1755-1315/1488/1/012012
[20] Sherin S, Raza S, Ahmad I. Conceptual framework for hazards management in the surface mining industry—application of structural equation modeling. Safety 2023;9:31. https://doi.org/10.3390/safety9020031
[21] Usman Mohammed, Shahmir Sivaraj Abdullah, Shuhymee Ahmad. Narratives of total quality management, green management, risk-taking on organizational performance: The moderating role of IT infrastructure. Multidisciplinary Science Journal, 2024;6. https://10.31893/multiscience.2024230
[22] Zhao Y, Qiu R, Chen M, Xiao S. Research on operational safety risk assessment method for long and large highway tunnels based on FAHP and SPA. Applied Sciences 2023;13:9151. https://doi.org/10.3390/app13169151
[23] Mahdinia M, Yarandi MS, Jafarinia E, Soltanzadeh A. Development of a new technique for safety risk assessment in construction projects based on fuzzy analytic hierarchy process. ASCE ASME J Risk Uncertain Eng Syst A Civ Eng 2021;7:04021037. https://doi.org/10.1061/AJRUA6.0001157
[24] Moloudi A, Khaloo SS, Gholamnia R, Saeedi R. Prioritizing health, safety and environmental hazards by integrating risk assessment and analytic hierarchy process techniques in solid waste management facilities. Arch Environ Occup Health 2022;77:598–609. https://doi.org/10.1080/19338244.2021.1977907
[25] Mousavi SM, Yazdanirad S, Althubiti S, Majdabadi MA, Najarian F, Sepehr P. Determination and prioritization of factors affecting the occurrence of needle stick injuries among healthcare workers using techniques of Delphi and fuzzy analytical hierarchy process (FAHP). BMC Public Health 2023;23:2009.
[26] Alqahtani FM, Noman MA. An integrated fuzzy Delphi and fuzzy AHP model for evaluating factors affecting human errors in manual assembly processes. Systems 2024;12:479. https://doi.org/10.3390/systems12110479
[27] Ketsakorn A, Kosolsaksakul P. Application of Delphi technique and analytic hierarchy process to prioritize the occupational health and safety management system requirements. Int J Occup Saf Health 2025;15:182–91. https://doi.org/10.3126/ijosh.v15i2.60760