Technema: Journal of Intelligent Engineering and Computing
Vol 1 No 2 June 2026, Hal 337-352
ISSN: 3163-6020 (Print) ISSN: 3163-5997 (Electronic)
Open Access: https://sovereignresearch.org/technema

Analysis of Potential Hazards in the Mining Area of PT Cakrawala Prima Manunggal Using the Hira Method

Muhammad Rafi Kaldi[1*], Rodiyah Nursani[2], Suhardiman Gumanti[3]
[1-3] Universitas Prabumulih, Indonesia
email: rafikaldi31@gmail.com[1]

Article Info :
Received:
14-06-2026
Revised:
27-06-2026
Accepted:
29-06-2026

Abstract

Mining activities involve various potential hazards that may cause occupational accidents, requiring systematic efforts to identify, assess, and control workplace risks. This study aims to identify potential hazards, analyze risk levels, and formulate risk control recommendations in the mining production area of PT Cakrawala Prima Manunggal. The study employed the Hazard Identification and Risk Assessment (HIRA) method through field observations, interviews, documentation, and literature review. Hazard identification was conducted across six operational areas, namely the workshop, parking area, front loading, main road hauling, disposal dumping, and stock ROM. Risk assessment was performed by evaluating likelihood and severity using the AS/NZS 4360 risk matrix. The results identified 17 potential hazards, consisting of 10 high-risk hazards (59%), 6 medium-risk hazards (35%), and 1 low-risk hazard (6%). High-risk hazards were primarily associated with road conditions, equipment maneuvering areas, safety berms, dust exposure, inadequate illumination, and disposal-area conditions. Recommended controls include the proper use of personal protective equipment, installation of safety signs and barriers, improvement of road and workplace conditions, dust suppression through water spraying, workplace organization, strengthened supervision, and continuous safety education and implementation of occupational safety and health procedures. These findings provide a systematic basis for prioritizing preventive interventions and strengthening occupational risk management in mining operations.

Keywords: *Hazard Identification and Risk Assessment (HIRA), Occupational Safety and Health, Potential Hazards, Risk Assessment, Risk Control.*

INTRODUCTION

Mining is one of the industrial sectors that contributes significantly to national economic development, yet it is simultaneously recognized as an occupational environment with a high potential for accidents because its operational activities combine complex machinery, hazardous materials, changing environmental conditions, and demanding work processes. The mining sector has long been identified as one of the most hazardous employment sectors globally, particularly because workers may be exposed to multiple interacting sources of occupational risk (Wijaya & Ramdhan, 2022). Mining activities involve heavy equipment, excavation, material transportation, blasting, unstable geological structures, dust, toxic gases, fires, explosions, and other physical and mechanical hazards that can produce severe consequences when preventive controls are inadequate (Anizar, 2012). Occupational safety and health management therefore requires a preventive framework capable of identifying hazards before they develop into accidents rather than relying primarily on corrective actions after incidents have occurred. This preventive orientation is consistent with the international occupational safety framework that emphasizes the systematic identification and management of workplace hazards as a fundamental component of effective occupational safety and health practices (International Labour Organization, 2015). The complexity of mining operations makes the quality of hazard identification particularly important because the interaction between workers, equipment, materials, and environmental conditions can create risk pathways that are difficult to recognize through routine supervision alone.

A systematic approach to hazard management is consequently required to translate potential hazards into measurable risks and prioritized control measures within mining operations. HIRA provides a structured process for identifying hazards, assessing their likelihood and severity, and determining appropriate controls according to the assessed level of risk. The fundamental logic of risk assessment is rooted in the systematic process of recognizing uncertainty, evaluating its potential consequences, and determining appropriate responses to reduce unacceptable exposure (Hanafi, 2006). Previous research has demonstrated that HIRA can be applied to high-risk industrial activities to identify hazardous work conditions and establish risk priorities that support more targeted safety interventions (Anthony, 2019). Evidence from fabrication activities also indicates that combining HIRA with task-oriented safety analysis can improve the identification of hazards by linking general workplace conditions with specific work processes (Herlina et al., 2022). The application of HIRA in industrial environments therefore extends beyond merely documenting hazards because the resulting risk classification can provide an analytical basis for determining which hazards require immediate control and which can be monitored through existing preventive measures. This analytical function is particularly relevant to mining environments in which numerous activities occur simultaneously and safety resources must be directed toward risks with the greatest potential consequences.

Recent mining studies further demonstrate that risk assessment needs to account for the specific characteristics of activities and work locations rather than relying solely on generalized industry-level assumptions. Research involving gold-mining workers in East Suwawa found that HIRA could identify potential accident hazards associated with actual mining activities and classify their corresponding risks, demonstrating the relevance of site-specific assessment in mining safety management (Ismail et al., 2023). A study of rolling stock equipment maintenance in an underground mining operation similarly showed that HIRADC could classify identified risks into low, medium, and high categories, allowing control priorities to be established according to the level of assessed risk (Markus & Djunaidi, 2024). A systematic review of mining research reported that HIRADC provides a relatively comprehensive framework because it integrates hazard identification, risk assessment, and risk control within a single analytical process (Susanto, 2024). The application of recognized risk-management standards, including AS/NZS 4360, provides an established foundation for evaluating risk through structured consideration of likelihood and consequences (Standards Australia/Standards New Zealand, 2004). Recent research has also begun integrating task-based safety analysis with risk assessment in mining activities, indicating a broader methodological movement toward more detailed and context-sensitive occupational risk analysis (Rinawiyanti et al., 2026).

Despite the growing application of HIRA and HIRADC, important limitations remain in the existing literature concerning the consistency and scope of hazard assessment across different mining contexts. The findings of a recent literature review indicate considerable variation in the approaches used to identify hazards, assess risk levels, and determine control measures across mining operations, suggesting that no single assessment framework is implemented uniformly across all operational contexts (Al Zhafir et al., 2026). Studies have frequently concentrated on particular activities or workstations, such as underground equipment maintenance, gold mining, sulfur mining, or individual production processes, which limits the transferability of their risk profiles to mining companies with different operational characteristics. Risk assessment can also become less informative when the classification process is detached from the actual sequence of work activities, equipment conditions, and environmental characteristics encountered by workers. The use of administrative measures and personal protective equipment may reduce exposure, but these controls cannot substitute for higher-level interventions when hazards can be eliminated, substituted, or controlled through engineering measures. Occupational safety management standards emphasize that systematic management should address both organizational requirements and operational hazards rather than treating safety as an isolated compliance activity (OHSAS Project Group, 2007). More comprehensive analytical approaches have consequently been proposed, including the integration of risk assessment with Fault Tree Analysis to examine relationships among hazardous events and their potential causal pathways in mining environments (Hutauruk & Ramli, 2026). These developments reveal a continuing empirical gap concerning how a systematic HIRA assessment can be applied to map the potential hazards of an entire mining area within a specific company whose operational risk profile has not previously been documented comprehensively.

The unresolved gap is scientifically and practically important because incomplete hazard identification can cause occupational safety management to become reactive, with control measures being strengthened only after accidents, near misses, or unsafe conditions have emerged. A systematic HIRA assessment can provide an evidence-based mechanism for determining the relative significance of hazards and establishing control priorities before those hazards develop into harmful events. Previous research in industrial settings has shown that structured hazard identification and risk assessment can support the selection of appropriate preventive measures by connecting identified hazards with their potential consequences and corresponding levels of risk (Irianingtyas et al., 2025). The importance of this preventive approach is reinforced by research on occupational risk in industrial production, where systematic identification and assessment are used to establish a basis for reducing exposure to workplace hazards (Lutfianto & Febrianti, 2021). Mining safety assessment should also consider environmental and occupational-health hazards because workers may face exposure risks that are not immediately visible but can produce adverse consequences through prolonged contact with hazardous substances or environmental conditions (Susanto et al., 2023). Effective risk control requires a hierarchy that prioritizes measures according to their capacity to remove or reduce the hazard rather than depending exclusively on worker behavior or personal protective equipment (Tarwaka, 2008). The effectiveness of such controls is also influenced by human-resource factors, including worker competence, behavior, discipline, and organizational practices within the workplace (Mangkunegara, 2002). Consequently, a site-specific analysis of PT Cakrawala Prima Manunggal is necessary to establish whether potential hazards within its mining area have been systematically recognized and prioritized according to their actual operational risks.

This research is positioned within the occupational safety and risk-management literature by applying HIRA to the mining area of PT Cakrawala Prima Manunggal, thereby connecting established risk-assessment principles with the empirical conditions of a specific mining operation. Rather than assuming that risk patterns reported in previous studies are directly applicable, the study examines potential hazards according to the activities, equipment, working conditions, and operational characteristics encountered within the research site. The analysis is intended to produce a structured identification of potential hazards and corresponding risk levels that can be used to establish priorities for occupational safety intervention. Previous research has demonstrated that HIRA can function as a practical instrument for reducing workplace accident risks when hazard identification and risk assessment are systematically connected with control planning (Rahmadiana, 2016). The study also recognizes that risk assessment is ultimately intended to support organizational decision-making by providing a rational basis for selecting appropriate preventive measures rather than merely producing numerical risk classifications. From a methodological perspective, the research contributes by demonstrating the application of HIRA as a site-specific diagnostic framework for a mining area in which comprehensive hazard documentation has not previously been established. From a theoretical perspective, it reinforces the application of proactive risk-management principles by examining how structured hazard identification and risk assessment can be operationalized within a real mining context, while its practical contribution lies in providing PT Cakrawala Prima Manunggal with an evidence-based basis for prioritizing controls and strengthening occupational safety management. The objective of this study is therefore to analyze the potential hazards present in the mining area of PT Cakrawala Prima Manunggal using the HIRA method and to develop a systematic risk profile that can support more proactive, targeted, and context-sensitive occupational safety management.

RESEARCH METHODS

This study employed an empirical field-based research design to identify, assess, and prioritize potential occupational hazards in the mining production area of PT Cakrawala Prima Manunggal using the Hazard Identification and Risk Assessment (HIRA) method. The research was conducted over a one-month period and covered six operational areas, namely the workshop, parking area, front loading, main road hauling, disposal dumping, and stock ROM, which were selected because they represent different work activities, equipment interactions, and environmental exposure conditions. Primary data were obtained through direct field observations, interviews and discussions with workers and relevant company personnel, documentation of workplace conditions, and information concerning occupational accidents, while secondary data consisted of company records and accident data for the January–May 2023 period. The observation focused on work activities, heavy-equipment movement, workplace layout, environmental conditions, unsafe acts, unsafe conditions, and potential events that could result in occupational injury or property damage. Interviews were used to clarify work procedures, existing safety practices, and hazardous conditions that could not be fully interpreted through observation alone, whereas photographic and documentary records were used as supporting evidence for the identified conditions. The collected data were organized according to operational area, work activity, hazard source, and potential consequence to establish a structured hazard inventory before risk assessment, consistent with the systematic identification principle applied in HIRA-based occupational safety studies (Herlina et al., 2022). The research workflow consisted of preliminary observation, literature review, field data collection, data classification, hazard identification, risk assessment, interpretation of risk levels, formulation of control recommendations, and conclusion development.

The HIRA assessment was conducted by assigning a Likelihood (L) score and a Severity (S) score to each identified hazard based on its potential occurrence and consequence, respectively. The risk score was calculated using Equation (1), where R represents the risk score, L represents likelihood, and L represents severity, following the quantitative risk-assessment principle of combining probability and consequence (Standards Australia/Standards New Zealand, 2004).

$$R = L\ X\ S\ (1)$$

Each of the 17 identified hazards was evaluated using a 1–5 scale for both likelihood and severity, producing risk scores that were subsequently mapped onto the HIRA risk matrix. The resulting scores were classified into Low Risk (L), Medium Risk (M), and High Risk (H) categories according to their corresponding positions within the matrix, allowing the hazards to be prioritized according to relative risk magnitude. Validation of the identification and assessment process was performed through triangulation among direct observations, interviews, company documentation, and historical accident records to reduce dependence on a single source of evidence. The proportion of hazards within each risk category was calculated using Equation (2), where P denotes the percentage of a particular risk category, n denotes the number of hazards within that category, and N denotes the total number of identified hazards.

$$P = \frac{n}{N}\ X\ 100\%\ (2)$$

descriptively by comparing the number and percentage of high-, medium-, and low-risk hazards across the six operational areas, while control recommendations were formulated according to the hierarchy of controls, prioritizing elimination, substitution, engineering controls, administrative controls, and personal protective equipment (OHSAS Project Group, 2007).

RESULTS AND DISCUSSION

Identification of Potential Hazards in the PT Cakrawala Prima Manunggal Mining Area

Field observations at PT Cakrawala Prima Manunggal identified 17 potential hazards distributed across six operational areas, comprising the workshop, parking area, front loading, main road hauling, disposal dumping, and stock ROM. The identified hazards emerged from differences in work activities, equipment movement, workplace layout, environmental conditions, housekeeping practices, and worker compliance with occupational safety requirements. Such variation indicates that hazard identification in mining operations needs to consider both direct sources of injury and the conditions that increase the probability of hazardous events during routine production activities (Anizar, 2012). The workshop generated four findings involving inadequate use of hand protection during welding, absence of safety helmets, scattered iron waste, and spilled oil. These conditions represent different hazard mechanisms, ranging from thermal and falling-object exposure to slip, trip, and contact hazards. The coexistence of several mechanisms within one work area indicates that workplace safety cannot be evaluated solely from the perspective of individual worker behavior because physical workplace conditions can independently contribute to accident occurrence. The identified hazards were therefore classified according to their operational location and potential consequences before proceeding to the HIRA risk assessment.

The detailed identification of the 17 findings is presented in Table 1, which links each operational area with the observed hazardous condition and its potential consequence. The table shows that the workshop and main road hauling each contain four identified hazards, while the parking area contains three hazards and the front loading, disposal dumping, and stock ROM areas contain two hazards each. This distribution indicates that the number of hazards is not necessarily determined by the size or complexity of an area, but by the degree of interaction among workers, mobile equipment, infrastructure, and environmental conditions. In the workshop, for example, the absence of gloves during welding creates direct exposure to sparks, whereas scattered iron waste and spilled oil generate indirect risks through unsafe housekeeping conditions. Research applying HIRA and JSA in industrial environments similarly demonstrates that combining activity-level observation with systematic hazard identification can reveal hazards arising from both work procedures and surrounding workplace conditions (Herlina et al., 2022). The findings in Table 1 therefore establish the empirical basis for determining whether particular conditions represent isolated unsafe situations or recurring risk patterns across the mining operation.

Table 1. Identification of Potential Hazards and Potential Consequences

Code	Operational Area	Identified Hazard	Potential Consequence
1A	Workshop	Worker does not use hand gloves during CCTV-pole welding	Hand injury from welding sparks
1B	Workshop	Worker does not use safety helmet during welding activities	Head injury from falling material or objects
1C	Workshop	Scattered iron waste	Tripping, cuts, and possible infection
1D	Workshop	Spilled oil drums/oil on the floor	Slipping and falling
2A	Parking Area	MG and DT parked too close and outside designated parking arrangement	Collision between units
2B	Parking Area	Slippery parking surface after rainfall	Loss of control and collision
2C	Parking Area	Scattered waste in parking area	Unsafe and uncomfortable working conditions
3A	Front Loading	Narrow maneuvering space at EX 02	Collision with dozer or other DT
3B	Front Loading	Uneven and undulating maneuvering surface at EX 05	DT instability or sinking
4A	Main Road Hauling	Inadequate berm at the road toward Front Seam E	DT leaving the road edge or falling
4B	Main Road Hauling	Thick dust along Front Loading Seam E	Collision between hauling units
4C	Main Road Hauling	Fallen boulder/material on the road	Vehicle damage or collision
4D	Main Road Hauling	Insufficient illumination	Collision and property damage
5A	Disposal Dumping	No protective berm at the northern disposal area	DT sinking or falling from the dumping edge
5B	Disposal Dumping	Inclined tower line near the unit access road	Falling structure and worker injury
6A	Stock ROM	Standing water	Slippery road and DT skidding
6B	Stock ROM	Thick dust at Stock ROM/Hauling CG	Collision between hauling DT units

The findings from the parking and front-loading areas further demonstrate that equipment interaction is a major source of potential risk within the operational environment. In the parking area, the proximity of MG and DT units creates a collision exposure that may become more pronounced when visibility, attention, or maneuvering space is reduced. The slippery surface following rainfall represents an environmental condition that can alter vehicle control characteristics and increase the possibility of contact between adjacent units. In the front-loading area, the narrow maneuvering space at EX 02 and the uneven surface at EX 05 indicate that road geometry and ground conditions can directly affect the stability and maneuverability of heavy equipment. Similar findings from mining research show that HIRA is useful for identifying hazards associated with specific mining activities and translating field observations into potential accident mechanisms (Ismail et al., 2023). These conditions are particularly relevant because mobile equipment operates with substantial mass and limited maneuvering tolerance, meaning that relatively minor deficiencies in road configuration can have disproportionate consequences. The identification stage therefore indicates that equipment-related hazards should receive substantial attention during the subsequent assessment of likelihood and severity.

The main road hauling area produced four hazards that are closely associated with transportation safety, namely an inadequate berm, thick dust, fallen material, and insufficient illumination. These conditions create interconnected risks because the effectiveness of vehicle operation depends simultaneously on road integrity, visibility, obstacle detection, and physical separation from hazardous edges. The inadequate berm at the route toward Front Seam E represents a deficiency in physical protection, while the presence of fallen material introduces an unexpected obstruction that can affect vehicles using the same route. Thick dust can further reduce visibility and limit the driver's ability to detect other hauling units, whereas inadequate illumination may intensify this limitation under low-light operating conditions. The concentration of these hazards within a single transportation corridor indicates that the main road hauling area represents an important risk concentration point within the mining operation. HIRA-based research in other industrial environments similarly demonstrates that risk identification becomes more meaningful when hazards are connected to specific operational activities and their possible consequences rather than recorded as generic workplace deficiencies (Anthony, 2019). The empirical findings therefore suggest that transportation-related hazards require assessment not only individually but also in terms of their potential interaction during simultaneous hauling operations.

The disposal dumping and stock ROM areas reveal additional hazards associated with physical safeguards and environmental conditions surrounding heavy-equipment operations. The absence of a protective berm at the northern disposal area creates a direct exposure to vehicle instability during reversing and dumping activities, while the inclined tower line introduces a potential falling-object hazard along a route used by mobile equipment. In the stock ROM area, standing water can reduce surface traction and increase the possibility of dump-truck skidding, whereas thick dust can restrict visibility during coal hauling operations. These findings demonstrate that mining hazards may originate from infrastructure and environmental conditions even when workers comply with established operating procedures. The importance of identifying such conditions is consistent with the preventive orientation of occupational safety management, which requires hazards to be recognized and controlled before they develop into harmful events (International Labour Organization, 2015). The recurring presence of road-surface, visibility, structural, and vehicle-interaction hazards across different areas indicates that the risk profile of PT Cakrawala Prima Manunggal is strongly influenced by the relationship between production activities and the physical mining environment. The 17 findings identified through field observation consequently provide the empirical input required for assigning likelihood and severity values in the subsequent HIRA assessment.

Risk Level Assessment Using the HIRA Matrix

The HIRA assessment transformed the 17 identified hazards into measurable risk levels by combining the likelihood of occurrence with the severity of potential consequences. The assessment produced three risk classifications, namely high, medium, and low, which provide a basis for differentiating hazards according to their relative urgency for intervention. This approach follows the principle that risk magnitude should be determined through systematic consideration of both the probability of an event and the consequences that may arise when the event occurs (Hanafi, 2006). The resulting distribution consisted of 10 high-risk findings, 6 medium-risk findings, and 1 low-risk finding, indicating that a substantial proportion of the observed conditions require more than routine monitoring. The predominance of high-risk findings is particularly important because several of them involve heavy mobile equipment, vehicle movement, inadequate physical safeguards, and restricted visibility, where an incident may produce severe consequences for workers and equipment. The assessment also demonstrates that hazard frequency alone cannot determine safety priorities because hazards with similar operational characteristics may receive different classifications depending on their likelihood and potential severity. The HIRA matrix therefore functions as an analytical mechanism for converting qualitative field observations into a prioritized risk structure.

The risk classification used in the assessment is presented in Table 2, where the intersection between likelihood and severity determines whether an identified condition is categorized as low, medium, or high risk. The matrix places greater emphasis on combinations involving high likelihood and high severity, which explains the concentration of several mining-traffic hazards within the high-risk category. The approach is consistent with AS/NZS 4360, which conceptualizes risk assessment as the systematic comparison of likelihood and consequences to determine the significance of identified risks (Standards Australia/Standards New Zealand, 2004). The resulting classification provides a common analytical scale for comparing hazards occurring in operationally different locations, such as workshops, hauling roads, loading areas, and disposal zones. It also prevents the assessment from treating every identified hazard as having equivalent importance, because the same type of unsafe condition may generate substantially different consequences depending on its operational context. In this study, the matrix consequently becomes the principal decision-support instrument for identifying which hazards require immediate attention from PT Cakrawala Prima Manunggal management.

Table 2. Risk Assessment Matrix for Occupational Accidents (HIRA)

	Severity				
Likelihood	1	2	3	4	5
5	M	M	H (1B, 2A, 2B)	H	H (4A, 4B, 4D, 6B)
4	L	M	M	H (3A, 5A, 6A)	H
3	L	M	M (1A, 1D, 3B, 5B)	M	H
2	L	L (2C)	M (1C)	M (4C)	M
1	L	L	L	L	M

Note: L = Low Risk; M = Medium Risk; H = High Risk.

The distribution of risk levels indicates that 58.82% of the identified hazards were classified as high risk, while 35.29% were classified as medium risk and 5.88% as low risk. The proportion of high-risk findings indicates that the mining area contains a considerable concentration of conditions capable of generating serious consequences when combined with relatively high probabilities of occurrence. High-risk findings include the absence or inadequacy of physical safeguards, unsafe positioning of mobile equipment, restricted maneuvering space, thick dust, insufficient illumination, and environmental conditions affecting vehicle stability. This pattern is comparable with mining safety research showing that structured HIRA or HIRADC assessments can reveal substantial variations in risk levels across operational activities and provide a basis for prioritizing corrective action (Markus & Djunaidi, 2024). The six medium-risk findings remain operationally relevant because their classification does not indicate that the associated hazards are acceptable or should be disregarded, but rather that their combination of likelihood and severity produces a lower priority than the high-risk conditions. The single low-risk finding, represented by scattered waste in the parking area, has a comparatively limited risk score, although continued housekeeping is still required to prevent deterioration of workplace conditions. The distribution therefore suggests that PT Cakrawala Prima Manunggal should allocate safety interventions according to risk magnitude while maintaining controls for lower-level hazards.

The high-risk category is concentrated particularly around activities involving heavy equipment and vehicle movement, with findings 1B, 2A, 2B, 3A, 4A, 4B, 4D, 5A, 6A, and 6B receiving the highest classification in the matrix. Several of these hazards involve situations in which a loss of vehicle control, inadequate visibility, or insufficient physical protection could produce consequences extending beyond a single worker to other operators, equipment, and operational infrastructure. The combination of high likelihood and high severity is particularly critical in mining because the physical scale and operating mass of dump trucks and other heavy units can amplify the consequences of relatively short deviations from safe operating conditions. A systematic review of mining risk assessment similarly identifies HIRADC as a comprehensive framework for connecting hazard identification with risk assessment and control prioritization in mining operations (Susanto, 2024). The high-risk findings should therefore not be interpreted merely as numerical outputs but as indicators of operational conditions where preventive intervention has the greatest potential to reduce accident exposure. The presence of thick dust at both the main road hauling and stock ROM areas is especially significant because reduced visibility can influence driver perception, following distance, and collision avoidance simultaneously. Likewise, the absence of an adequate berm in the hauling and disposal areas represents a structural deficiency that cannot be effectively addressed through worker caution alone. The risk classification consequently identifies engineering and environmental controls as important priorities for the high-risk conditions.

The medium-risk category comprises 1A, 1C, 1D, 3B, 4C, and 5B, reflecting hazards whose likelihood or severity is lower than the combinations classified as high risk but which remain capable of causing occupational injury or equipment damage. The workshop findings in this category illustrate how housekeeping and personal protective behavior can generate measurable occupational exposure even when the potential consequences are generally more localized. In contrast, the medium-risk classification of the fallen boulder on the main hauling road reflects a transportation hazard whose consequences can become more severe when combined with vehicle speed, poor visibility, or inadequate driver response. Previous HIRA research has shown that medium-level risks can still require defined control measures because their classification represents a relative priority rather than an absence of danger (Irianingtyas et al., 2025). The inclined tower line in the disposal area also demonstrates why medium-risk classification should not be interpreted as a justification for delayed action when the hazard involves potentially unstable infrastructure. Risk assessment is most effective when the classification is followed by a control strategy that addresses the underlying source of the hazard rather than merely documenting its existence. The medium-risk findings therefore remain relevant to the overall safety system because uncontrolled medium risks may increase in severity when operational or environmental conditions change.

The low-risk category contains only finding 2C, referring to scattered waste in the parking area, and its position in the matrix indicates a relatively limited combination of likelihood and severity compared with the other identified hazards. Although the immediate consequence is primarily associated with reduced workplace order and discomfort, poor housekeeping can become a precursor to more serious conditions when waste accumulates, obstructs movement, or interacts with vehicle operations. Occupational safety management emphasizes that workplace conditions should be systematically maintained because minor unsafe conditions can contribute to broader accident pathways when they remain uncontrolled (OHSAS Project Group, 2007). The classification also demonstrates the analytical value of HIRA because not every observed deficiency is automatically assigned the same priority, allowing management attention to be concentrated on conditions with greater potential consequences. At the same time, the low classification should not be understood as an exemption from corrective action, particularly when the cost of housekeeping intervention is relatively low and the measure can prevent deterioration of workplace conditions. The risk hierarchy established by the assessment therefore distinguishes intervention urgency while maintaining the principle that identified hazards should remain under appropriate control. The results provide a quantitative basis for moving from hazard recognition toward area-level comparison and identification of the operational locations that contribute most strongly to the overall risk profile.

The HIRA assessment establishes that the principal safety concern at PT Cakrawala Prima Manunggal is not the mere presence of hazards but the concentration of high-risk conditions within activities involving heavy equipment, transportation routes, loading, dumping, and environmental exposure. The 10 high-risk findings represent 58.82% of the total observations, creating a risk profile in which immediate preventive attention should be directed toward conditions capable of producing severe consequences. This interpretation is consistent with the preventive safety principle that risk assessment should support decisions concerning which hazards require priority treatment rather than functioning solely as a documentation procedure (Lutfianto & Febrianti, 2021). The assessment also provides an empirical bridge between observed workplace conditions and subsequent control recommendations because each risk category can be traced to a specific operational hazard and potential consequence. The resulting pattern indicates that engineering conditions, traffic management, visibility control, road maintenance, and physical barriers are likely to be more strategically important than isolated reliance on personal protective equipment. The findings further support the need to examine risk distribution across the six operational areas because the overall percentage of high-risk findings may conceal differences in the concentration and characteristics of hazards between locations. Area-level analysis is therefore required to determine where risk is most concentrated and which operational mechanisms should receive priority within the company's occupational safety management system.

Distribution and Critical Analysis of Occupational Risk Across Operational Areas

The distribution of identified risks across the six operational areas shows that occupational risk at PT Cakrawala Prima Manunggal is concentrated in activities involving heavy-equipment movement, transportation, loading, dumping, and environmental exposure. The Main Road Hauling area recorded the largest number of high-risk findings, with three of its four identified hazards classified as high risk, followed by the Parking Area and Stock ROM, each with two high-risk findings. This distribution indicates that operational mobility is a dominant characteristic underlying the risk profile because workers and equipment are repeatedly exposed to collision, visibility, road-condition, and vehicle-control hazards. Similar patterns have been identified in mining research, where equipment movement and activity-specific operating conditions represent important sources of potential occupational accidents (Ismail et al., 2023). The Workshop contained four hazards but only one high-risk finding, indicating that the number of identified hazards does not necessarily correspond directly to the severity of the overall risk profile. Conversely, the two hazards identified in the Stock ROM generated two high-risk classifications, showing that a smaller number of hazards can represent a greater safety concern when their likelihood and consequences are both substantial.

The area-level distribution is summarized in Table 3, which provides a comparison between the number of high-, medium-, and low-risk findings within each operational area. The table shows that Main Road Hauling accounts for three of the ten high-risk findings, making it the most prominent high-risk location in the assessment. Parking Area and Stock ROM each contribute two high-risk findings, while Workshop, Front Loading, and Disposal Dumping each contribute one high-risk finding. The concentration of high-risk conditions in transportation-related areas is consistent with the broader understanding that mining operations require systematic assessment of hazards arising from the interaction between mobile equipment, infrastructure, and workplace conditions (Al Zhafir et al., 2026). The distribution also reveals that Workshop has the highest total number of findings together with Main Road Hauling, yet its risk profile is comparatively less severe because three of its four hazards fall into the medium-risk category. This distinction is important for managerial decision-making because intervention priorities should be based on risk magnitude rather than simply on the number of hazards recorded. The resulting distribution provides a clearer basis for identifying operational areas where engineering and administrative controls should be strengthened.

Table 3. Distribution of Risk Levels by Operational Area

Operational Area	High Risk	Medium Risk	Low Risk
Workshop	1	3	0
Parking Area	2	0	1
Front Loading	1	1	0
Main Road Hauling	3	1	0
Disposal Dumping	1	1	0
Stock ROM	2	0	0
Total	**10**	**6**	**1**

The Main Road Hauling area represents the most critical operational zone because its three high-risk findings are associated with an inadequate berm, thick dust, and insufficient illumination, while an additional medium-risk finding concerns material falling onto the travel route. These hazards have a common characteristic in that they can directly interfere with the driver's ability to maintain vehicle control, detect obstacles, or maintain a safe trajectory along the hauling route. The combination of environmental visibility constraints and inadequate physical road protection creates a potentially interconnected risk pathway in which one unsafe condition can increase the consequences of another. Research on occupational risk assessment in industrial environments demonstrates that HIRA is particularly useful when hazards are evaluated according to the specific activities and operational conditions in which they occur rather than treated as generic workplace deficiencies (Irianingtyas et al., 2025). The presence of heavy dust can reduce visibility between hauling units, while insufficient illumination may produce a similar limitation under low-light conditions, making these two hazards relevant to the same accident mechanism. The inadequate berm represents a different but complementary risk because it concerns the physical containment of vehicles operating near potentially hazardous edges. The combination indicates that risk reduction in this area requires integrated management of road infrastructure, visibility, traffic conditions, and physical safeguards rather than isolated corrective measures.

The Parking Area presents a different risk configuration in which two high-risk findings arise from the interaction between vehicle positioning and surface conditions. The inappropriate proximity of MG and DT units can reduce maneuvering tolerance, while a slippery surface after rainfall can further compromise vehicle control during departure from the parking position. The fact that both conditions were classified as high risk indicates that the parking area should not be regarded merely as a support facility but as an operational environment requiring formal traffic and safety controls. The low-risk classification assigned to scattered waste in the same area demonstrates the distinction between environmental housekeeping issues and hazards that directly affect heavy-equipment movement. Previous research has shown that systematic HIRA assessment can differentiate risk levels within the same workplace and thereby provide a more rational basis for determining intervention priorities (Anthony, 2019). The Stock ROM area exhibits an even more concentrated pattern because both identified hazards, standing water and thick dust, were classified as high risk. These findings indicate that environmental conditions in the Stock ROM can directly influence vehicle stability and visibility, making environmental control an important component of mobile-equipment safety.

The Workshop presents four identified hazards, with one high-risk and three medium-risk findings, reflecting a risk profile that is more diverse than the transportation areas. The high-risk finding concerns the absence of a safety helmet during welding activities, while the medium-risk findings involve inadequate glove use, scattered iron waste, and spilled oil. These findings combine personal exposure with housekeeping deficiencies, indicating that workshop safety depends on both worker protection and the physical organization of the work environment. The presence of scattered metal and spilled oil can create secondary hazards even when the primary activity is controlled, because workers may encounter slip, trip, or contact risks while moving through the area. A previous study applying HIRA and JSA demonstrated that hazards arising from work activities and surrounding workplace conditions should be considered together when constructing an occupational risk profile (Herlina et al., 2022). Front Loading and Disposal Dumping each contain two identified hazards, with one high-risk and one medium-risk condition, suggesting a balanced distribution between immediate high-priority hazards and conditions requiring continued control. These areas nevertheless remain strategically important because both involve heavy equipment operating in environments where restricted maneuvering space, unstable surfaces, or inadequate physical safeguards can rapidly increase accident consequences.

The area-level comparison demonstrates that risk concentration is strongly related to the interaction between mobile equipment and the physical mining environment rather than merely to the number of work activities performed within an area. Main Road Hauling has the greatest concentration of high-risk findings, while Stock ROM has the highest proportion of high-risk conditions relative to its total findings, indicating that both frequency and risk intensity should be considered when allocating safety resources. The finding is compatible with the view that mining risk assessment should integrate hazard identification, risk classification, and control determination within a single systematic framework (Susanto, 2024). From an operational perspective, transportation routes require particular attention because hazards such as dust, inadequate illumination, fallen material, and deficient berms can affect several vehicle operators simultaneously. The results also indicate that environmental conditions should be incorporated into routine risk monitoring because rainfall, dust generation, and surface deterioration can modify the risk level of an activity even when the underlying work procedure remains unchanged. This characteristic supports a dynamic interpretation of HIRA in which risk assessment should remain responsive to changes in workplace conditions rather than being treated as a one-time documentation exercise. The observed distribution therefore establishes a clear basis for prioritizing control measures in Main Road Hauling, Parking Area, and Stock ROM while maintaining appropriate preventive measures across Workshop, Front Loading, and Disposal Dumping. Such prioritization is important because effective occupational safety management depends on directing intervention toward hazards with the greatest potential consequences while preserving control over lower-level risks (OHSAS Project Group, 2007).

The comparison across operational areas also reveals that high-risk conditions are not confined to a single type of mining activity, but emerge through several mechanisms that include vehicle interaction, inadequate engineering safeguards, restricted visibility, unstable surfaces, and unsafe workplace arrangements. This finding strengthens the interpretation that the company's risk profile is multidimensional and cannot be adequately addressed through a single type of intervention. The concentration of high-risk hazards around hauling and mobile-equipment activities also corresponds with the broader mining safety literature, which emphasizes the importance of integrating activity-specific risk assessment with systematic control strategies (Hutauruk & Ramli, 2026). The results provide an empirical basis for distinguishing between hazards that require immediate engineering intervention and those that can be addressed through administrative measures, housekeeping, or strengthened worker compliance. In particular, inadequate berms, insufficient illumination, restricted maneuvering areas, and unstable physical structures represent conditions where source-level intervention is more appropriate than relying primarily on individual worker caution. The distribution further suggests that risk controls should be coordinated across operational areas because hauling activities connect parking, front loading, main road, disposal, and stock ROM operations into a continuous movement system. A hazard originating in one area can therefore influence risk in another area when mobile equipment, materials, or environmental conditions move through interconnected operational routes. The next stage of analysis consequently focuses on translating these risk classifications into specific control recommendations that address the identified hazards according to their risk level and operational mechanism.

Risk Control Recommendations Based on the HIRA Assessment

The identification and classification of 17 hazards provide the basis for determining control measures that are proportionate to the risk characteristics of each operational activity. Risk control in this study follows the principle that corrective action should prioritize intervention at the hazard source before relying on worker behavior or personal protective equipment. The hierarchy of controls provides a structured basis for selecting measures through elimination, substitution, engineering controls, administrative controls, and personal protective equipment, with the higher levels generally providing more fundamental risk reduction (OHSAS Project Group, 2007). The results indicate that several high-risk conditions at PT Cakrawala Prima Manunggal originate from deficiencies in physical infrastructure, environmental conditions, and equipment interaction rather than from individual worker behavior alone. Such findings make engineering and administrative interventions particularly relevant for controlling hazards associated with hauling roads, loading areas, disposal zones, and stock ROM operations. Risk control should also consider the operational feasibility of each intervention because mining activities require continuous equipment movement and cannot be managed effectively through measures that substantially disrupt essential production processes.

The recommended controls were therefore formulated by relating each identified hazard to its potential accident mechanism and corresponding level of risk. The recommended control priorities for the identified hazards are presented in Table 4, which links the observed conditions with proposed interventions based on the characteristics of each operational area. The table emphasizes physical and engineering measures for hazards involving vehicle stability, road configuration, visibility, and structural integrity, while administrative measures and personal protective equipment are positioned as supporting controls. This approach is consistent with established occupational safety principles that emphasize reducing exposure through changes in the workplace or work process rather than relying exclusively on individual worker compliance (Tarwaka, 2008). For the workshop, controls include enforcing appropriate hand and head protection, improving housekeeping, and removing spilled oil and sharp metal waste from active work zones. In the hauling and disposal areas, priority measures include improving berms, controlling dust, maintaining road surfaces, improving illumination, removing fallen materials, and securing unstable structures. The recommendations are intended to reduce the probability of hazardous events at their source while simultaneously limiting the severity of consequences should an incident occur.

.

Table 4. Recommended Risk Controls for Identified Hazards

Code	Operational Area	Hazard	Recommended Control
1A	Workshop	Worker does not use hand gloves during welding	Mandatory welding gloves, PPE inspection, and safety supervision
1B	Workshop	Worker does not use safety helmet	Mandatory safety helmet and PPE compliance monitoring
1C	Workshop	Scattered iron waste	Routine housekeeping and designated waste-storage areas
1D	Workshop	Spilled oil	Immediate spill cleanup and designated oil-storage arrangements
2A	Parking Area	MG and DT parked too close	Separate parking zones and regulated parking layout
2B	Parking Area	Slippery surface after rainfall	Drainage improvement, surface maintenance, and speed control
2C	Parking Area	Scattered waste	Routine housekeeping and waste collection
3A	Front Loading	Narrow DT maneuvering area	Improve maneuvering space and establish traffic-management controls
3B	Front Loading	Uneven and undulating surface	Road leveling, grading, and periodic surface inspection
4A	Main Road Hauling	Inadequate berm	Construct and maintain berm according to applicable mining requirements
4B	Main Road Hauling	Thick dust	Water spraying, dust suppression, and visibility monitoring
4C	Main Road Hauling	Fallen material/boulder	Routine road inspection and immediate material removal
4D	Main Road Hauling	Insufficient illumination	Install and maintain adequate lighting at critical road sections
5A	Disposal Dumping	No protective berm	Construct adequate dumping-edge berm and establish dumping controls
5B	Disposal Dumping	Inclined tower line	Stabilize or relocate the tower and restrict access to the hazard zone
6A	Stock ROM	Standing water	Improve drainage and maintain dry, stable hauling surfaces
6B	Stock ROM	Thick dust	Dust suppression and traffic-management measures

The Main Road Hauling and Disposal Dumping areas require particular emphasis on engineering controls because several identified hazards originate from inadequate physical safeguards. The inadequate berm at the road toward Front Seam E and the absence of a protective berm at the northern disposal area should be addressed through construction and periodic inspection of berms capable of providing effective physical protection against vehicle departure from the designated route. The need for such measures is supported by recent mining research emphasizing comprehensive risk identification and control for hazards associated with rock and heavy-equipment operations (Hutauruk & Ramli, 2026). The inclined tower line in the disposal area should also be stabilized, relocated, or isolated from areas where workers or mobile equipment may be exposed to falling-structure hazards. Road conditions at Front Loading EX 05 should be improved through grading and compaction to reduce the possibility of dump-truck instability during maneuvering. These interventions address the physical sources of risk rather than requiring operators to compensate for deficient infrastructure through increased caution. Engineering controls are particularly important in this context because physical deficiencies may persist even when workers demonstrate appropriate safety awareness.

Environmental conditions constitute another major control priority because thick dust, standing water, slippery surfaces, and insufficient illumination can modify the safety characteristics of mining operations. Dust suppression through regular water spraying should be implemented at Main Road Hauling and Stock ROM, accompanied by monitoring of visibility during periods of intensive hauling activity. Standing water at Stock ROM should be controlled through improved drainage and routine inspection of road surfaces so that water accumulation does not reduce tire traction. Insufficient illumination along Main Road Hauling requires installation and maintenance of lighting at locations where visibility is inadequate, particularly at areas involving frequent interaction between hauling units. Environmental health risks in mining and mineral-processing environments can also emerge through exposure to hazardous environmental conditions, indicating the importance of incorporating environmental factors into occupational risk management (Susanto et al., 2023). These controls should be integrated into routine operational inspections rather than implemented only after an incident occurs. The effectiveness of environmental controls should be monitored through observable indicators such as road visibility, surface condition, drainage performance, and adequacy of illumination.

Administrative controls remain necessary for hazards involving equipment interaction, maneuvering, parking arrangements, and worker compliance with established safety requirements. The Parking Area should use clearly separated parking zones for MG and DT units, supported by directional signs and standardized parking procedures to reduce unnecessary interaction between mobile equipment. The narrow maneuvering area at Front Loading EX 02 requires traffic-management arrangements that define equipment movement paths, maintain adequate separation, and reduce simultaneous maneuvering where space is insufficient. Routine inspection of hauling routes should also be incorporated into operational procedures so that fallen boulders or other obstructions can be identified and removed before they interfere with vehicle movement. Research on occupational safety management demonstrates that systematic assessment and control planning can strengthen preventive safety practices by linking identified hazards with specific operational interventions (Lutfianto & Febrianti, 2021). Administrative measures should be supported by regular supervision because procedures that are not monitored may gradually lose their effectiveness during repetitive production activities. The combination of traffic management, inspection routines, supervision, and worker communication can therefore strengthen the consistency of controls across interconnected mining activities.

Personal protective equipment remains necessary for residual risks that cannot be fully eliminated through engineering or administrative measures, particularly in workshop activities involving welding and material handling. Workers performing welding activities should be required to use appropriate welding gloves, safety helmets, and other task-specific protective equipment, while supervisors should conduct routine PPE compliance inspections before and during work. The findings involving missing gloves and helmets indicate that PPE non-compliance remains a relevant contributor to occupational exposure, although PPE should function as the final layer of protection rather than the principal solution to unsafe workplace conditions. Previous research on HIRA-based occupational safety management indicates that identification and assessment should be followed by control measures that correspond to the characteristics and magnitude of the identified risks (Krida & Nugroho, 2024). Housekeeping should also be institutionalized through scheduled cleaning and designated waste-storage locations to prevent iron waste and oil spills from creating secondary hazards. Workers should receive task-specific safety communication concerning welding hazards, equipment interaction, vehicle maneuvering, and emergency response procedures. The effectiveness of these measures depends on continuous supervision and documentation so that repeated non-compliance can be identified and addressed before it develops into an accident mechanism.

The control strategy developed from the HIRA findings indicates that PT Cakrawala Prima Manunggal requires a layered safety system combining engineering, environmental, administrative, housekeeping, and PPE-based interventions. This approach is consistent with the preventive orientation of occupational safety management, in which risk reduction is achieved by controlling hazards before exposure produces an accident or occupational injury (International Labour Organization, 2015). The priority should be directed toward the ten high-risk findings, particularly those involving berm deficiencies, vehicle interaction, thick dust, inadequate illumination, unstable surfaces, and restricted maneuvering conditions. Medium-risk findings should remain subject to routine corrective action because changes in operational conditions can increase their likelihood or severity, while the low-risk housekeeping finding should be controlled through regular workplace maintenance. The proposed measures also provide a practical connection between the numerical HIRA assessment and operational safety management because each risk classification is translated into an identifiable intervention. A structured control program can support management in monitoring whether corrective actions have been implemented and whether the original hazardous conditions have been reduced. The analytical value of HIRA therefore extends beyond risk classification by providing a framework for prioritizing interventions according to the relationship between hazard source, likelihood, severity, and feasible control. This control-oriented interpretation is consistent with research demonstrating that systematic hazard identification and risk assessment can serve as a foundation for reducing occupational accident exposure across industrial and mining environments (Rahmadiana, 2016).

CONCLUSION

The study identified eight types of potential hazards across the mining production activities at PT Cakrawala Prima Manunggal, comprising tripping, sparks, pollution, scratches, falling objects, punctures, slipping, and falling hazards. These hazards were identified across 17 work activities and workplace conditions distributed among the workshop, parking area, front loading, main road hauling, disposal dumping, and stock ROM areas. The HIRA assessment classified the identified hazards into three risk categories, consisting of 10 high-risk hazards, 6 medium-risk hazards, and 1 low-risk hazard. The high-risk category represented 59% of the identified hazards, indicating that a substantial proportion of the observed conditions requires priority attention from the company's occupational safety management. The medium-risk category accounted for 35%, while the low-risk category accounted for 6%, showing that risk exposure remains present across different levels of operational severity. The findings demonstrate that hazards associated with heavy-equipment interaction, workplace conditions, road infrastructure, visibility, and worker practices constitute important safety concerns within the assessed mining areas. The HIRA approach provides a systematic basis for distinguishing risk priorities and supporting more targeted occupational safety interventions within the company's operational environment.

Risk control should prioritize measures that address hazards at their source while maintaining appropriate administrative controls and personal protective equipment as complementary safeguards. Recommended interventions include the provision and consistent use of appropriate PPE, such as safety shoes, gloves, workwear, safety glasses, face shields, helmets, and other equipment corresponding to specific work activities. The company should also strengthen safety communication through clear warning signs, traffic and hazard markings, routine safety briefings, and continuous education concerning occupational safety and health procedures. Supervisors and management should conduct regular monitoring, inspection, and evaluation of operational activities to ensure that established safety procedures are consistently implemented. Particular attention should be directed toward the high-risk findings because uncontrolled exposure to these hazards may increase the probability of occupational accidents and their potential consequences. Future research may extend the present assessment by integrating HIRA with other analytical approaches, such as Job Safety Analysis, Fault Tree Analysis, or more quantitative risk-assessment techniques, to obtain a more detailed representation of accident mechanisms. Continuous cooperation between management and workers is essential for maintaining effective hazard control and developing a proactive safety culture across the mining operation.

REFERENCES

Al Zhafir, H., Nandito, J., & Ulya, I. (2026, January). Implementation of Occupational Health and Safety Using the Hiradc Method (Hazard Identification, Risk Assessment, and Determining Control) In Mining Areas: Literature Review. In *International Conference of Public Health* (pp. 246-251). https://journal.utu.ac.id/index.php/ICPH/article/view/176

Anizar. (2012). *Teknik Keselamatan dan Kesehatan Kerja Di Industri*. Yogyakarta: Graha Ilmu.

Anthony, M. B. (2019). Analisis Risiko Kerja pada Area Hot Metal Treatment Plant Divisi Blast Furnace dengan Metode Hazard Identification and Risk Assessment (HIRA). *Jurnal INTECH Teknik Industri Universitas Serang Raya*, *5*(1), 35-42. https://doi.org/10.30656/intech.v5i1.1461

Hanafi, M. (2006). *Manajemen Risiko.* Yogyakarta: Unit Penerbit dan Percetakan Sekolah Tinggi Ilmu Manajemen YKPN.

Herlina, L., Dewantari, N. M., Sonda, A., & Mulyana, M. R. (2022). Hazard identification in fabrication industry using Hazard Identification and Risk Assessment (HIRA) and Job Safety Analysis (JSA). *Journal Industrial Servicess*, *8*(2), 170-175. https://dx.doi.org/10.36055/jiss.v8i2.17112

Hutauruk, I. S. B., & Ramli, M. (2026). Enhancing Occupational Safety in Rock Mining: A Comprehensive Hazard Identification, Risk Assessment, and Risk Control and Fault Tree Analysis. *International Journal of Safety & Security Engineering*, *16*(2), 447. https://doi.org/10.18280/ijsse.160218

International Labour Organization. (2015). *International labour standards on occupational safety and health*. International Labour Organization.

Irianingtyas, R., Bimantara, A., Chahyadhi, B., & Rahmania, N. E. N. (2025). Analysis of occupational safety and health risk management in metal industry production areas using the hira method. *Nurse and Health: Jurnal Keperawatan*, *14*(2), 10-20. https://doi.org/10.36720/nhjk.v14i2.874

Ismail, S. I. C., Irwan, I., & Lalu, N. A. S. (2023). Analysis of Potential Hazards for Work Accidents Using the Hira (Hazard Identification and Risk Assessment) Method on Gold Mine Workers in East Suwawa District. *Journal Health & Science: Gorontalo Journal Health and Science Community*, *7*(1), 99-107. https://doi.org/10.35971/gojhes.v7i1.16187

Krida, G. M., & Nugroho, A. J. (2024). Analisis Kesehatan dan Keselamatan Kerja pada Produksi Pabrik Tahu Pak Rahman dengan Menggunakan Metode Hazard Identification And Risk Assesment (HIRA). *JURNAL ILMIAH NUSANTARA*, *1*(4), 822-832. https://doi.org/10.61722/jinu.v1i4.1940

Lutfianto, A. R. N. Q., & Febrianti, M. A. (2021, November). Management Analysis on Occupational Health and Safety in the Boiler House Using Method of Hazard Identification, Risk Assessment and Determining Control. In *2021 Third International Sustainability and Resilience Conference: Climate Change* (pp. 358-361). IEEE. https://doi.org/10.1109/IEEECONF53624.2021.9668034

Mangkunegara. (2002). *Manajemen Sumber Daya Manusia.* Bandung: Rosda Karya.

Markus, A., & Djunaidi, Z. (2024). Hazard identification, risk assessment and determining control (HIRADC) pada kegiatan perawatan rolling stock equipment di tambang bawah tanah PT. X. *Jurnal Ilmiah Manajemen, Ekonomi, & Akuntansi (MEA)*, *8*(2), 479-497. https://doi.org/10.31955/mea.v8i2.4002

OHSAS Project Group. (2007). *OHSAS 18001:2007 Occupational Health and Safety Management Systems—Requirements*. OHSAS Project Group.

Rahmadiana, A. A. (2016). *Hazard Identification And Risk Assessment Sebagai Upaya Mengurangi Resiko Kecelakaan Kerja Dan Resiko Penyakit Akibat Kerja Dibagian Produksi PT Iskandar Indah Printing*. (Skripsi, UNIVERSITAS Muhammadiyah Surakarta). https://eprints.ums.ac.id/46958/

Rinawiyanti, E. D., Kusumo, A. H., Irawan, F. C., & Dewi, D. R. S. (2026). Integrating job safety analysis and risk assessment for occupational safety in task-based sulfur mining activities. *Jurnal Rekayasa Sistem Industri (JRSI)*, *15*(1), 93-105. https://doi.org/10.26593/jrsi.v15i1.10088.93-105

Rivai dkk (2009). Rivai, Veithzal dan Sagala, Ella Jauvani. *Manajemen Sumber Daya Manusia untuk Perusahaan*. Jakarta: PT Raja Grafindo Persada.

Standards Australia/Standards New Zealand. (2004). *AS/NZS 4360:2004 risk management*. Standards Australia/Standards New Zealand.

Susanto, A., Zannah, M., Putro, K., Manuel, A. A., Yochu, W. E., & Mahlisa, R. (2023, August). Assessment of Environmental Health Risks Associated with Chemical Content of Drinking Water for Workers in the Copper and Gold Mineral Ore Processing Industry. In *E3S Web of Conferences* (Vol. 448, p. 03001). EDP Sciences. https://doi.org/10.1051/e3sconf/202344803001

Susanto, A. (2024). Tinjauan Literatur Sistematis: Identifikasi Bahaya, Penilaian Risiko dan Pengendalian Risiko Pada Operasi Pertambangan. *Jurnal Manajemen Kesehatan Yayasan RS. Dr. Soetomo*, *10*(2), 446-460. https://doi.org/10.29241/jmk.v10i2.2065

Tarwaka. (2008). *Keselamatan dan Kesehatan Kerja*. Surakarta: Harapan Press.

.

Wijaya, M. Y. T., & Ramdhan, D. H. (2022). Studi kasus kecelakaan kerja akibat gas beracun tambang bawah tanah: Literature review. PREPOTIF: Jurnal Kesehatan Masyarakat, 6(2), 1373−1378. https://doi.org/10.31004/prepotif.v6i2.4266