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Hazard and Operability Study Analysis of Potential Hazards In Gold Mining Processes at PT. J Resources Bolaang Mongondow

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Abstract

The gold mining industry presents a complex risk profile due to the interaction between human factors, heavy machinery, and extreme environmental conditions. This study aims to analyze potential hazards and assess operational risks in the gold mining process at PT. J Resources Bolaang Mongondow using the Hazard and Operability Study (HAZOP) method. This study applies the HAZOP method—typically used in chemical industries—to identify operational deviations in the open-pit mining sector, specifically focusing on the interaction between fatigue and environmental factors in tropical climates. This study applies the HAZOP method to identify operational deviations in the open-pit mining sector, uniquely focusing on how the combination of fatigue (micro-sleep), extreme tropical rainfall, and operational deviations (overload and mobile phone use) drives extreme risks. This research employed a qualitative method with a descriptive design. Data were collected through field observations, document reviews, and in-depth interviews with Safety Supervisors, Safety Officers, and unit operators. Data analysis followed HAZOP procedures: node determination, deviation identification using guide words, and risk assessment using the AS/NZS 4360:1999 matrix. The study identified a total of 127 potential hazards across six mining processes (Land Clearing, Drilling & Blasting, Loading, Hauling, Dumping, and Crushing). The risk assessment revealed 19 "Extreme" level risks, dominated by physiological factors (fatigue/micro-sleep), environmental factors (slippery roads due to rain), and operational deviations (overload and unauthorized communication device usage). Controlling mining risks requires a systemic approach—combining engineering controls (such as installing objective load sensors), management strategies (upgrading communication infrastructure), and a strong safety culture (reinforcing 'Stop Work Authority')—rather than merely enforcing individual compliance.

KEYWORDS

occupational health and safety; HAZOP; risk management; gold mining; fatigue.

Introduction

According to data from the Ministry of Manpower (Satudata Kemnaker, 2023), work accidents in Indonesia reached 462,241 cases in 2024, a significant surge compared to the 370,747 cases recorded in 2023. This massive increase indicates that the implementation of the Occupational Health and Safety Management System (SMK3) across industries requires urgent evaluation(Ahad & Saldy, 2020; Novita et al., n.d.).

PT. J Resources Bolaang Mongondow, specifically at the Bakan Site, operates using an open-pit method. This method presents unique challenges, particularly regarding slope stability and equipment maneuverability in variable weather conditions. Previous data and field observations indicate that fatigue and environmental conditions (slippery roads) are recurrent issues

(Aditama & Hastuti, 2021; Mokodompis, 2020). For instance, internal fatigue check data from the EHS Department between 2018 and 2019 recorded at least 15 incidents where operators had to be relieved due to severe fatigue and loss of focus, which are critical precursors to fatal accidents.

The purpose of this study is to analyze potential hazards in the mining process using the Hazard and Operability Study (HAZOP) method. Unlike standard risk assessments, HAZOP systematically reviews processes to determine whether deviations from the design intent can lead to undesirable events(Alijoyo et al., n.d.; Kotek & Tabas, 2012). This study focuses on identifying deviations in six key mining processes: Land Clearing, Drilling & Blasting, Loading, Hauling, Dumping, and Crushing(Agincourt Resources, 2021; Kurniawan & Yuliani, 2021). By formulating the problem through the lens of process deviation, this research aims to provide a more granular understanding of accident causation, moving beyond "human error" to identify systemic operational failures(Djainal & Djou, 2021; Saputra, 2020).

Previous studies at this location, such as Latief, (2021), primarily focused on the relationship between physical workload and fatigue. Other studies have identified unsafe conditions primarily through standard hazard identification checklists(Aprilia et al., 2020; Irawan & Setyowati, 2022). However, there is a lack of research examining how these human factors dynamically interact with process deviations(Restuputri et al., 2021; Sobirin & Zaqi Al Faritsy, 2023). This study fills that gap by utilizing HAZOP to map process deviations in detail, moving beyond the simplistic labeling of "human error" to uncover underlying systemic operational failures(Ramadhan & Fitriani, 2024).

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Methods

The method is elaborated to enhance the analysis approach and steps taken to identify deviations in the mining workflow.

Research Type

This study used a qualitative approach with a descriptive design(Irwan, 2017). The qualitative method was chosen to explore the depth of information regarding complex potential hazards and to understand the behavioral and environmental contexts influencing risks, as supported by HAZOP principles which rely on brainstorming and deep analysis of process deviations(Agil & Kholil, 2022). Calculating the Risk Level by multiplying Likelihood and Consequence scores based on the (AS/NZS 4360:1999, 1999) matrix. The hazard identification and scoring were conducted through Focus Group Discussion (FGD) sessions involving the Safety Supervisor, Safety Officer, and representatives of unit operators. Disagreements in scoring were resolved through consensus based on historical incident data and daily observation logs.

Population and Sample/Informants

The informants were selected using purposive sampling techniques to ensure they possessed the necessary technical knowledge(Heryana, 2018; Irwan, 2021). The key informant was the Safety Supervisor (1 person), supported by the Safety Officer (1 person) as an additional informant. The main data sources for operational deviations were the unit operators (5 persons) covering Excavator, Crusher, Liugong, HDT, and ADT units, who are directly involved in the daily operations.

Research Location

The research was conducted at PT. J Resources Bolaang Mongondow, located in Bakan Village, Lolayan District, Bolaang Mongondow Regency, North Sulawesi. The site is characterized by hilly topography and high rainfall, providing a specific context for analyzing environmental hazards in open-pit mining.

Instrumentation or Tools

The primary instrument was the researcher, aided by observation checklists, interview guides, and the HAZOP Worksheet. The study also utilized the AS/NZS 4360:1999 Risk Management Standard matrix to determine the Likelihood (L) and Consequences (C) of identified hazards(Soputan et al., 2020; Tjakra et al., 2020).

Data Collection Procedures

Data collection was carried out from November to December 2024. The procedures included:

1. Observation: Direct observation of the mining processes from land clearing to crushing to identify unsafe conditions and actions.
2. Interviews: In-depth interviews to validate findings and understand the root causes of deviations (e.g., why operators use phones or why overload occurs).
3. Documentation: Review of SOPs, accident data, and company risk profiles.

Data Analysis

Data analysis followed the HAZOP methodology steps:

1. Node Determination: The mining process was divided into 6 nodes: Land Clearing, Drilling & Blasting, Loading, Hauling, Dumping, and Crushing.
2. Deviation Identification: Using "Guide Words" (e.g., More, Less, No, Other Than) combined with parameters (e.g., Load, Rest, Rainfall) to identify deviations.
3. Risk Assessment: Calculating the Risk Level by multiplying Likelihood and Consequence scores based on the AS/NZS 4360:1999 matrix. The risk levels were determined by consolidating data from field observations and in-depth interviews with the Safety Supervisor and operators. The matrix scales Likelihood from 1 (Rare) to 5 (Almost Certain), and Consequence from 1 (Insignificant) to 5 (Catastrophic). The final risk rating is the product of these two factors.
4. Recommendation: Proposing controls for identified risks.

Result and Discussion

The results section presents the key findings of the HAZOP analysis. The study identified a total of 127 potential hazards. The distribution of risks across the mining processes is summarized below.

Risk Distribution and Identification

The HAZOP analysis revealed that the "Hauling" and "Land Clearing" processes had the highest number of potential hazards due to the dynamic nature of moving equipment and environmental unpredictability. The HAZOP analysis revealed that the "Hauling" and "Land Clearing" processes had the highest number of potential hazards due to the dynamic nature of moving equipment and environmental unpredictability. For example, hauling presents high risks (24 hazards) due to the continuous interaction of heavy-duty trucks with steep, unpaved haul roads that degrade rapidly during sudden tropical downpours. Furthermore, extreme deviations like overload ("More Load") frequently occur in the loading process when operators are forced to rely purely on their intuition ("feeling") without weigh scales to meet fast loading cycles, which drastically increases the risk of brake failure on downhill slopes. (See table 1).

Key HAZOP Findings (Extreme Risks)
The analysis highlighted 19 Extreme Risks that require immediate systemic intervention. The hazard identification and scoring were agreed upon through Focus Group Discussion (FGD) sessions involving the Safety Supervisor, Safety Officer, and operators, supported by historical incident data and daily observation logs. The key deviations identified include:

Deviation: Less Rest (Fatigue)
a. Node: All Processes (especially Hauling & Drilling).
b. Cause: Irregular sleep patterns, high workload, and production pressure. During interviews, operators confirmed they are often reluctant to use their "Stop Work Authority" due to the pressure of meeting ritase targets.
c. Consequence: Micro-sleep leading to loss of unit control and fatal accidents.
d. Risk Level: Extreme (Likelihood 5 x Consequence 4). Based on the AS/NZS 4360:1999 rubric, a Likelihood of 5 indicates the event occurs frequently (more than once a month), while a Consequence of 4 means it could lead to severe injuries resulting in 3 or more lost workdays.

Deviation: More Load (Overload)
a. Node: Loading, Hauling, Dumping.
b. Cause: Lack of objective load indicators (e.g., no onboard payload monitoring systems on excavators or trucks), reliance on operator "feeling", and pressure to meet hourly production targets as reported by operators.
c. Consequence: Brake failure, unit rollover, and severe structural damage.
d. Risk Level: Extreme (Likelihood 5 x Consequence 3). A Likelihood of 5 indicates frequent occurrence (more than once a month), and a Consequence of 3 indicates moderate severity requiring hospitalization with less than 3 lost workdays, alongside significant financial loss due to equipment damage.

Deviation: More Rainfall (Slippery Road)
a. Node: Land Clearing, Hauling, Dumping.
b. Cause: Heavy tropical rain combined with delayed grader response to clear the mud, exacerbated by the dynamic and unpaved conditions of the open-pit haul roads.
c. Consequence: Heavy-duty units sliding, collisions, and total production stoppage.
d. Risk Level: Extreme (Likelihood 5 x Consequence 4). Similar to fatigue, the Likelihood of 5 reflects the high frequency of extreme weather in this tropical site, and a Consequence of 4 reflects the severe impact and potential for permanent disability if a sliding unit rolls over.

Deviation: Other Than Concentration (Use of Mobile Phone)
a. Node: Loading, Hauling, Dumping.
b. Cause: Boredom and unclear radio communication signals (blank spots), which force operators to use personal devices for rapid coordination, as admitted during in-depth interviews.
c. Consequence: Visual and cognitive distraction leading to collisions in heavy equipment blind spots.
d. Risk Level: Extreme (Likelihood 4 x Consequence 4). A Likelihood of 4 indicates it happens easily and frequently (at least once a month to once a year), while a Consequence of 4 highlights the severe potential for fatal blind-spot collisions resulting in 3 or more lost workdays.

The discussion interprets the findings within the context of existing research and explores practical implications.

Fatigue and Production Pressure
Our findings revealed that fatigue is a systemic hazard across all mining nodes. Operators confirmed that micro-sleep is a major threat, particularly during night shifts. This finding supports previous research by Latief (2021) at the same location. Crucially, our study found that fatigue is heavily exacerbated by production pressures. During interviews, the Safety Supervisor acknowledged that the pressure to meet production targets often makes operators reluctant to report fatigue or use their "Stop Work Authority"(Mahdang & Mokodompis, 2021).

Equipment Overload
The identification of Overload as an Extreme Risk highlights a critical technological gap. Interviews with Loader operators revealed that the absence of objective load indicators on buckets forces them to load based on "feeling". Driven by the demand for fast loading cycles to hit targets, this consistent deviation ("More Load") compromises vehicle stability and leads to brake fading during downhill hauling(Putri et al., 2021; Sasmito Aji & Jufriyanto, 2023).

Environmental Hazards (Rainfall)
The environmental factor of Slippery Roads ("More Rainfall") confirms the critical role of support units like graders. Hauling operators identified slippery downhill roads as their biggest fear, as it frequently causes sliding. As noted by Rifandi et al., (2022), slope stability in open-pit mines is highly dynamic. Our HAZOP analysis emphasizes that delays in grader response during moderate to heavy rainfall create a critical deviation leading to loss of unit control.

Communication Failures (Phone Use)
Unlike standard hazard identification, HAZOP allowed us to pinpoint that "Other Than Concentration" (using mobile phones) is not merely a disciplinary issue. Operators admitted to using personal phones primarily because the official radio communication signals were often unclear or contained blank spots. This indicates a symptom of poor communication infrastructure, necessitating an equipment upgrade rather than just administrative sanctions.

Table 1. Summary of Risk Levels per Mining Process

No	Process Node	Extreme Risk	High Risk	Moderate Risk	Low Risk	Total Hazards
1	Land Clearing	2	9	10	4	25
2	Drilling & Blasting	2	12	6	3	23
3	Loading	4	10	4	1	19
4	Hauling	4	11	8	1	24
5	Dumping	4	9	8	0	21
6	Crushing	3	8	3	1	15
Total		**19**	**59**	**39**	**10**	**127**

Source: Primary Data Analysis (2025)

Conclusion

This study investigated potential hazards in gold mining using the HAZOP method and aimed to analyze operational deviations. The findings demonstrated that out of 127 identified hazards, 19 were classified as Extreme Risks. These critical risks are dominated by physiological factors (fatigue/micro-sleep), environmental conditions (slippery roads due to rain), and operational deviations (overload and mobile phone usage).

The results underscore the need for a systemic approach to safety. It is not sufficient to rely solely on administrative controls or PPE(Prabowo & Yarsila, 2019). The study recommends: (1) implementing objective Load Indicators (onboard payload monitors) on heavy equipment to specifically target "More Load" deviations, thereby reducing the risk of brake failures and rollovers(Pratama & Wibowo, 2023); (2) strengthening the Fatigue Management Program with a non-punitive "Stop Work" culture to directly address "Less Rest" deviations and prevent micro-sleeps; and (3) upgrading Radio Communication infrastructure to target "Other Than Concentration" deviations, ensuring operators do not rely on personal mobile phones during critical operations(Darytaqy et al., 2023; Nurfadillah & Basri K, 2022; Nurfadillah & Maksum, 2021).

A limitation of this study is its reliance on qualitative risk assessments based on interviews and field observations. Future research should integrate objective fatigue measurement technologies and quantitatively evaluate the correlation between production targets and the frequency of unsafe acts.

Author contributions

Mohammad Quraisy Al-idrus conducted the field research, data collection, and drafted the original manuscript. Ayu Rofia Nurfadillah supervised the research design, methodology, and reviewed the risk assessment analysis and manuscript editing. Irwan assisted in data validation and HAZOP worksheet verification.

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Conflict of interest

The authors declare no conflict of interest regarding the publication of this article. The authors have no financial or personal relationships with entities that might unduly affect their objectivity.

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