RISK MITIGATION HIGHEST RISK LEVEL (RED ZONE) BASED ON HAZARD IDENTIFICATION RISK ASSESSMENT AND ASSESSMENT (HIRARC)

UNDERGRADUATE THESIS

Submitted to the International Undergraduate Program in Industrial Engineering in Partial Fulfilment of Requirement for the Degree of Sarjana Teknik at the Faculty of Industrial Technology
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YOGYAKARTA
2025

AUTHENTICITY STATEMENT

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Yogyakarta, July 27th, 2025



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RESEARCH COMPLETION LETTER



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DEDICATION PAGE

I sincerely dedicate this thesis to:

My beloved parents, for their love, unwavering moral and spiritual support, and trust that always encourages me to achieve my dreams. Your prayers and wise sayings have shaped me into a disciplined, diligent, and unyielding person.

My supervisors, who have guided me in designing the research methodology, analyzing hazard identification and risk control data, and providing constructive feedback at every stage of writing. Your guidance has improved the technical and scientific quality of this research.

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MOTTO

“O you who believe, seek help from Allah with patience and prayer. Verily, Allah is with those who are patient." (Q.S Al-Baqarah: 153)

” Allah does not burden anyone except according to his ability.” (Q.S Al-Baqarah:286)

“For surely after hardship there is ease, surely after hardship there is ease." (QS. Al-Inshirah: 5-6).

PREFACE

Alhamdulillah, all praise and gratitude to Allah SWT for His grace, gifts, and guidance so that the research and preparation of the final project report entitled "Mitigation Highest Risk Level (Red Zone) Based on Hazard Identification Risk Assessment and Risk Control (HIRARC)" can be completed properly. Shalawat and salam may always be poured out to our lord, the Prophet Muhammad SAW, along with his family, friends, and all his people who always inspire our steps towards goodness. The writing of this final project is one of the academic requirements to obtain a Bachelor of Industrial Engineering degree at Universitas Islam Indonesia. In the process of preparing this report, the author gained a lot of valuable knowledge and experience, both in terms of risk management theory and its application in the mining industry. Therefore, the author would like to express his deepest gratitude to:

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ABSTRACT

The rate of work accidents in the mining industry is still relatively high despite the implementation of various safety systems. Coal transportation activities with heavy equipment and extreme road conditions are one of the main contributors to the risk of fatal accidents. This study aims to identify and evaluate the risks that are classified as very high at PT. XYZ uses the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method, and formulates mitigation strategies in the form of preventive actions and contingency plans to reduce risk levels and maintain the company's operational sustainability. Through risk assessment using a matrix, 21 risk variables were found to be categorized as very high (red zone), with the two main risks being slippery roads during rain and operators not knowing the landslide zone. The cause analysis was conducted using a fishbone diagram, and then mitigation measures were developed based on the risk control hierarchy. The results showed that the integrated implementation of technical and administrative controls and the use of personal protective equipment can significantly reduce potential hazards. This study concludes that systematic risk management through the HIRARC approach is effective in mapping hazard priorities and determining appropriate mitigation measures. The main recommendations are aimed at improving engineering controls, operator training, and emergency response plan readiness to prevent future work accidents.

Keywords: Coal Mining, OSH, HIRARC

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CHAPTER I
INTRODUCTION

1.1 Background

According to the International Labor Organization (ILO), every year, there are more than 250 million accidents at work, and more than 160 million workers become ill due to workplace hazards. Moreover, 1.2 million workers die from accidents and illnesses at work (International Labour Organization, 2018). According to data from the Ministry of Energy and Mineral Resources (ESDM), the number of workplace accidents in the mining industry in 2023 was 217, with 48 incidents causing fatalities (Pramita, 2024).

Mining Occupational Safety and Health involves managing workplace safety, occupational health, the work environment, and management systems to keep workers safe and healthy. The mining sector, especially in coal and heavy equipment operations, has a much higher level of risk compared to other industries due to the hazardous nature of its activities. One of the most important processes in the mining sector is the hauling process. Hauling in the mining industry is the process of transporting the finished product from the pit to the processing facility, storage area, or port for further distribution. This process involves the use of heavy haulage equipment such as large trucks or conveyors specifically designed to transport large quantities of coal (Drury, Porter, & Dempsey, 2022).

However, despite the commitment to OHS, the facts on the ground show that the risk of workplace accidents remains high, especially in hauling and road maintenance activities. These activities not only involve human interaction with heavy equipment in extreme environmental conditions but also demand complex coordination and risk control. Such risks include operator fatigue hazards, vehicle collisions, poor road conditions, and truck braking or control system failures that could potentially lead to fatal accidents. Therefore, a systematic approach to risk identification, assessment, and control is required to minimize the severity of accidents that may occur in the work area (OHSAS18001, 2007).

One method that can be used to manage these risks is Hazard Identification, Risk Assessment, and Risk Control (HIRARC). This method plays an important role in identifying potential hazards in the workplace, assessing the level of risk based on its likelihood and impact, and formulating appropriate control measures. Through the HIRARC approach, risks that have the highest risk level values can be identified more

objectively, so that companies can prioritize effective mitigation actions (OHSAS18001, 2007).

The implementation of HIRARC at PT. XYZ does not merely aim to fulfill regulatory requirements but is also part of an important risk management strategy to improve operational effectiveness, protect labor safety, and reduce the potential for disruption of the production process due to work accidents. For this reason, comprehensive mitigation efforts are needed for risks with the highest level of danger, through the implementation of preventive actions and contingency plans, so that the company's operational sustainability can be guaranteed and a work safety culture can be increasingly embedded in all lines of the organization.

1.2 Problem Formulation

The following are problem formulation of this research:

1. What risks are classified as a very high level based on the results of the risk assessment at PT. XYZ?
2. What are the appropriate mitigation actions, both in the form of preventive actions and contingency plans, to reduce the risk level from the very high category?

1.3 Research Objectives

The following are the research objectives of this research:

1. Evaluate the risks at PT. XYZ that fall into the “very high” category based on the red zone on the risk matrix.
2. Propose mitigation actions, both in the form of preventive actions and contingency plans, which are appropriate to reduce the level of risk so that the company's operations can run more safely and sustainably.

1.4 Benefits of research

1.4.1 Benefit for academics

1. Contribute to the development of science in the field of occupational safety and health (OHS), especially in the application of the HIRA method in high-risk industries.

2. Become a reference for further research that wants to examine the relationship between the OHS program and the reduction in the number of work accidents quantitatively.

1.4.2 Benefit for the company

1. Become an objective basis for companies in assessing the success of implementing work safety programs, especially the HIRARC method.
2. Providing information on the factors causing the decrease in work accidents, so that management can make data-based strategic decisions.
3. Help identify gaps in the risk control system that still need to be improved so that the decrease in accidents is not only temporary.

1.5 Research Limitation

The following are limitations of this research:

1. Research Object

   This research was conducted at PT. XYZ, a coal mining company located in Kalimantan. The research focused on hauling and road maintenance.

2. Time Period

   The work accident data used in this study is limited to the last two years, namely 2023 and 2024, to determine the trends and causes of the decline in the number of work accidents.

3. Method Used

   The research only uses the HIRA (Hazard Identification and Risk Assessment) method in the process of identifying and analyzing occupational risks.

4. Type of Data

   The data used consists of work accident reports, direct observations in the field, as well as interviews and questionnaires given to employees and the OSH team at the company.

1.6 Systematic research

The research is structured into several chapters, and each chapter will be described as follows:

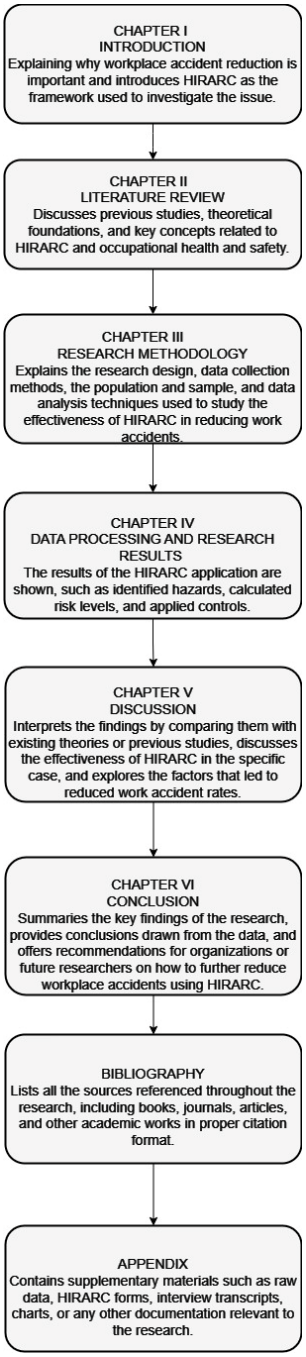


Figure 1. 1 Systematic research

CHAPTER II

LITERATURE REVIEW

2.1 Literature Review

Table 2. 1 Literature Review

No.	Title	Objectives	Methods	Result
1.	Evaluation of the Effectiveness of Using HIRARC (Hazard Identification, Risk Assessment, And Risk Control in Reducing Work Accidents in the Production Section at PT.Pertamina Rokan Hulu, Duri, Riau Year 2023 (Enindra, 2023)	This study describes the evaluation of occupational safety risks in the production section of PT Pertamina Rokan Hulu using the HIRARC method.	HIRARC	Statistics show a significant reduction in the number of workplace accidents after the implementation of HIRARC, but continued commitment is needed to ensure workplace safety in the future.
2.	Improving Work Safety Performance at PT. X With HIRARC Method On Loading and Hauling Activities (Gushady, 2025)	Identifying hazards, risk assessment, and risk control in an effort to minimize work accidents at PT X.	HIRARC	Of the 29 activities assessed, 10.34% were categorized as extreme risk and 17.24% as high risk. After risk control analysis, extreme risk decreased by 100%, and high risk decreased by 80% to the low category, with an increase in low risk from 2 to 27 (up 92%) indicating the effectiveness of risk control. This shows that the existence of these three activities, namely hazard identification, risk assessment, and risk control at PT X can be a way to reduce the risk of work accidents and improve work safety in loading and hauling activities.
3.	ANALYSIS OF ACCIDENT RISK MANAGEMENT SYSTEM WITH HIRARC	The purpose of this research is to analyze the Safety and Health	HIRARC	Research results Risk management of PT Bukit Asam, Tbk references Bukit Asam

No.	Title	Objectives	Methods	Result
	METHOD (HAZARD IDENTIFICATION RISK ASSESSMENT AND RISK CONTROL) PT BUKIT ASAM, TBK MINING UNIT TANJUNG ENIM, SOUTH SUMATERA (Masyruroh, 2020)	Management System using the HIRARC (Hazard Identification Risk Assessment and Risk Control) method to reduce the number of accidents.		Management System guidelines: BAMSM.00, OHSAS 18001:2007 clause 4.3.1 on hazard identification, risk assessment, and control determination and PP 50 of 2012 on the implementation of the Occupational Safety and Health Management System. Controls are carried out and effectively reduce the number of accidents, namely the value obtained is 4 medium risk and 14 Low risk.
4.	Correlational analysis of occupational accidents and the safety policies in the Chinese coal mining industry from 2008 to 2021 (Zhu, Wang, Liu, Zhu, & Lei, 2024).	This study investigates the correlation between previous coal mine safety policies and accidents in China.	Safety Policy	The study finds that safety policies have some impact on accident occurrence in coal mines. Although there has been a decrease in accidents and deaths over time, higher mortality rates are observed during periods of increased production intensity and on weekends.
5.	ANALYSIS OF POTENTIAL HAZARDS FOR WORK ACCIDENTS USING THE HIRA (HAZARD IDENTIFICATION AND RISK ASSESSMENT) METHOD ON GOLD MINE WORKERS IN EAST SUWAWA DISTRICT (Ismail & Irwan, 2023)	The purpose of the study was to analyze the Potential Hazards and Risk Assessment of work accidents with the HIRA method for Gold Mine Workers.	HIRA	The results showed that every job at the Gold Mine has potential hazards consisting of mechanical, physical and chemical hazards. There are 2 risks in the Very High category, 7 risks in the Priority 3 category, 2 risks in category 1, 9 risks in the Acceptable category and 12 risks

No.	Title	Objectives	Methods	Result
				in the Substantial category. The most common risks identified were object throwing (13.93%), slipping and falling from heights (12.61%), vehicle accidents (11.19%), and dust inhalation (9.53%). All jobs carried unacceptable risks (RPNs > 100), but they
6.	Hazard Identification and Risk Assessment of Occupational Activities in Golgohar Mining Company, Southeast Iran (2021) (Hasheminejad, Zare, Farahbakhsk, Bamir, & Zolala, 2022)	Investigate occupational hazards and perform a risk assessment in Golgohar mine no. 1. In the present study, JSA and FMEA methods were used to identify risks and rank risk levels	Job Safety Analysis (JSA), FMEA	were brought down to an acceptable level by implementing interventions. Conclusion: Proper hazard identification and control can prevent mining accidents. Regular risk assessments and worker training can support this goal.
7.	Implementation of OSH Risk Management among SMEs in Malaysia: A Systematic Literature Review (Marzuki, Majid, Rosman, & Mohamad, 2022)	investigated the implementation of the occupational safety and health (OSH) risk management system, known as the Hazard Identification, Risk Assessment and Risk Control (HIRARC), in small-medium enterprises (SMEs) in Malaysia.	HIRARC	The results show that there was scant work on the HIRARC system implementation and limited specific industries, such as construction and production.

2.2 Theoretical basis

2.2.1 Occupational Safety and Health

According to the International Labor Organization (ILO), OSH is an effort to improve and maintain the highest degree of physical, mental, and social well-being of all workers

in all types of employment (Astono, et al., 2019). This includes the prevention of occupational health disorders, as well as the protection of workers from risks that may harm their health. Occupational safety and health (OSH) in mining, especially during the hauling process, is a significant concern due to the inherent risks linked to material transportation. The hauling process presents considerable challenges that can impact worker safety, operational efficiency, and overall productivity.

The hauling process presents considerable risks that can impact worker safety, operational efficiency, and overall productivity. The risks in the hauling process are vehicle accidents, environmental hazards, and fatigue. Hauling operations frequently involve large, heavy vehicles like dump trucks and excavators. Accidents can occur because of driver fatigue, poor visibility, and difficult road conditions. A study revealed that hauling is the leading cause of fatal accidents in coal mining operations, emphasizing the need for stringent safety measures during these activities (Utama, 2024) (Caburao, 2024).

2.2.2 Work Accident

Work accidents are a major concern in many industries, particularly high-risk ones like construction, manufacturing, and mining. A work accident is an unexpected event that causes physical or mental harm to an employee while performing job-related activities. A work accident in mining is defined as any unexpected event that occurs while working at a mining site and causes injury, illness, or death to a worker. This includes incidents that occur while performing job-related tasks or engaging in activities directly related to mining operations (Cruz-Ausejo, Cama-Ttito, Solano, Copez-Lonzoy, & Vera-Ponce, 2024).

2.2.3 Hazard Identification Risk Assessment, and Risk Control (HIRARC)

Hazard Identification Risk Assessment, and Risk Control (HIRARC) is a method of preventing or minimizing work accidents. HIRARC is a method that starts by determining the type of work activity, which then identifies the source of the hazard, so that the risk can be assessed. Then, risk assessment and risk control will be carried out to reduce exposure to hazards contained in each type of work (Cruz-Ausejo, Cama-Ttito, Solano, Copez-Lonzoy, & Vera-Ponce, 2024).

According to AS/NZS 4360: 1999, risk is the chance of something happening that will have an impact on the target, measured by causal law. Risk is measured based on the likelihood and consequence values. Risk assessment is an assessment process used to identify potential hazards that could occur. The purpose of risk assessment is to ensure that the risk control of the process, operation, or activity carried out is at an acceptable level. The assessment in risk assessment is Likelihood (L) and Severity (S), or Consequence (C). Likelihood shows how likely the accident is to occur, while Severity or Consequence shows how severe the impact of the accident is. The value of Likelihood and Severity will be used to determine the Risk Rating or Risk Level.

The first step in HIRARC is the identification of hazards. A hazard can be defined as a condition, situation, or action that can cause damage, including accident, illness, death, pollution, and damage to a business facility. In the first stage, hazard identification is performed to identify all potential hazards, whether they come from materials, devices, or working systems. The five (5) factors for the sources of endangered species surrounding are people, methods, materials, machines, and the surrounding areas. After determining the source of hazard in the workplace, the next step is to conduct a risk assessment. This step is taken to determine the probability/risk associated with the identified risk. In this standard, two parameters are used for risk assessment. That is, probability/probability of risk and the severity of risk. The following is a consequence table, likelihood table, and risk matrix according to the AS/NZS 4360: 2004 standard:

Table 2. 2 Probability or Likelihood Criteria

Level	Criteria	Description
1	Rare	Almost never happened
2	Unlikely	Rarely happening
3	Possible	Can happen every once in a while
4	Likely	Often occur
5	Almost Certain	Can happen anytime

Table 2. 3 Severity Criteria

Level	Criteria	Description
1	Insignificant	No injury and or disease caused and or no effect on the environment, small financial loss
2	Minor	Minor injury and or illness with mild symptoms and or small effect on the environment, small financial loss.

Level	Criteria	Description
3	Moderate	Moderate injury and or chronic illness requires medical treatment and or moderate effect on the environment, sizeable financial loss.
4	Major	Serious injury and or chronic illness require medical treatment and or serious long-term.
5	Catastrophic	Fatal and or chronic disease require serious medical treatment and or very serious and long-term environmental damage, huge losses and very broad impacts, cessation of all activities.

From both parameters in Table 2.2 and Table 2.3, the risk assessment matrix level can be obtained as shown in Table 2.4.

Table 2. 4 Risk matrix

Likelihood	Severity				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)	M	H	VH	VH	VH
Likely (4)	L	M	H	VH	VH
Possible (3)	L	M	H	VH	VH
Unlikely (2)	L	L	M	H	VH
Rare (1)	L	L	M	H	H

Source: Risk assessment matrix adopted from AS/NZS 4360: 2004 standard.

According to Occupational Safety and Health, risk can be calculated using the following formula:

Risk (R) = L x S

where: L = likelihood

S = severity

CHAPTER III
RESEARCH METHOD

3.1 Research Subject

The subject of this research is PT. XYZ, which is a coal mining company operating in the hauling and road maintenance section located in Barunang, Kapuas Tengah, Kapuas Regency, Central Kalimantan.

3.2 Research Object and Timeline

The object of this research is the decrease in the number of work accidents at PT. XYZ.

3.3 Data Collection Method

Data in this research used several methods as follows:

1. Observation

   This data collection method is to collect data based on direct observation of what is happening in the field. The thing that was observed was the work process of the company, and data was collected about work accidents in the company.

2. Questionnaire

   This questionnaire contains questions related to risk control that already exist at PT. XYZ was distributed to 92 respondents.

3. Interview

   This method is done by conducting questions and answers or discussions directly with the Head of the SHE Department to get deeper insight.

4. Literature Review

   This method is employed by looking for references from previous research or that have been done to help or as a reference in research.

3.4 Research Method

This research uses the HIRARC method (Hazard Identification, Risk Assessment, and Risk Control), which is a method used to systematically manage risks in the workplace. Hazard Identification Risk Assessment and Risk Control (HIRARC) is a process of identifying hazards that can occur in both routine and non-routine activities and then carrying out an assessment process based on the hazards or risks that have been identified to determine the high and low value of a risk, so that it helps in the control process. In its

preparation, HIRA itself is divided into 3 stages, including the hazard identification stage and the risk assessment stage (Salguero-Caparros, Pardo-Ferreira, Martinez-Rojas, & Rubio-Romero, 2020).

3.4.1 Hazard Identification

A hazard is defined as a potential source of damage or harm to someone or something. Hazard identification is the first step in risk management and safety planning, which aims to locate and record possible hazards so that they can be assessed and controlled to prevent accidents and injuries. This process can be carried out through various methods such as workplace inspections, job safety analysis, incident investigations, employee reporting, and review of records. It is an ongoing activity that should be conducted during the design and implementation of new processes, before and during tasks, after incidents, and regularly through inspections (OSHA O. , 2020).

3.4.2 Risk Assessment

This process can be carried out through various methods such as workplace inspections, job safety analysis, incident investigations, employee reporting, and review of records. It is an ongoing activity that should be conducted during the design and implementation of new processes, before and during tasks, after incidents, and regularly through inspections. Risk assessment is the process of analyzing the probability (likelihood) of an incident occurring due to a hazard and the potential consequences (severity) of the incident. This evaluation helps quantify the magnitude of risk associated with each hazard. (Ministry of Human Resources, 2008). In this standard, two parameters are used for risk assessment. That is, probability/probability of risk and severity of risk. The following is a consequence table, likelihood table and risk matrix according to the AS/NZS 4360: 2004 standard.

Table 3. 1 Probability or Likelihood Criteria

Level	Criteria	Description
1	Rare	Almost never happened
2	Unlikely	Rarely happening
3	Possible	Can happen every once in a while
4	Likely	Often occur
5	Almost Certain	Can happen anytime

Table 3. 2 Severity Criteria

Level	Criteria	Description
1	Insignificant	No injury and or disease caused and or no effect on the environment, small financial loss
2	Minor	Minor injury and or illness with mild symptoms and or small effect on the environment, small financial loss.
3	Moderate	Moderate injury and or chronic illness requires medical treatment and or moderate effect on the environment, sizeable financial loss.
4	Major	Serious injury and or chronic illness require medical treatment and or serious long-term.
5	Catastrophic	Fatal and or chronic disease require serious medical treatment and or very serious and long-term environmental damage, huge losses and very broad impacts, cessation of all activities.

From both parameters in Table 3.1 and Table 3.2, the risk assessment matrix level can be obtained as shown in Table 3.3.

Table 3. 3 Risk matrix

Likelihood	Severity				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)	M	H	VH	VH	VH
Likely (4)	L	M	H	VH	VH
Possible (3)	L	M	H	VH	VH
Unlikely (2)	L	L	M	H	VH
Rare (1)	L	L	M	H	H

Source: Risk assessment matrix adopted from AS/NZS 4360: 2004 standard.

According to Occupational Safety and Health, risk can be calculated using the following formula:

Risk (R) = L x S

where: L = likelihood

S = severity

3.4.3 Risk Control

Risk control is the final and crucial step in the HIRARC (Hazard Identification, Risk Assessment, and Risk Control) process, which aims to eliminate or minimize the risks that have been identified and assessed in the workplace to prevent accidents and health hazards. The objective of risk control in occupational health and safety is to implement measures that reduce the likelihood and/or severity of potential risks to a level considered acceptable. Effective risk control not only minimizes the likelihood of accidents and

injuries occurring but also plays an important role in preventing the recurrence of work-related incidents.

Risk control measures are generally applied in a hierarchical order, known as the hierarchy of control, which prioritizes the most effective interventions. The first and most preferred approach is elimination, which involves completely removing the hazard from the work environment (OSHA, 2025). Risk control measures typically adhere to a hierarchy, prioritizing the most effective methods, including:

a. Elimination: Completely eliminate the hazard from the workplace.
b. Substitution: Replace the hazard with a less dangerous option.
c. Engineering controls: Use physical means to isolate people from the hazard (for example, machine guards, ventilation).
d. Administrative control: Changes to how people work, such as training, procedures, scheduling, and signage.
e. Personal Protective Equipment (PPE): Provides safety equipment to reduce exposure to hazards.

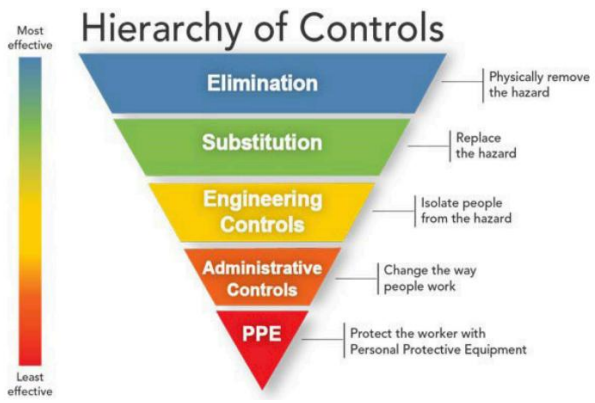


Figure 3. 1 Hierarchy of Controls

Source: NIOSH

3.5 Research Flow

The following is the research flow of this research.

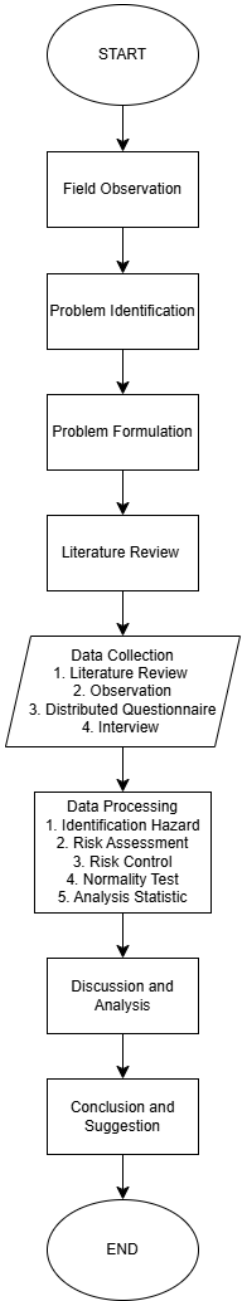


Figure 3. 2 Research Flow

Based on the research flow picture, the following are explanations of the research flow:

1. Start

   Understand things related to research, starting from the research flow to the output that will be produced.

2. Field Observation

   Make direct observations in the field to find out the problems that exist.

3. Problem Identification

   Identify problems that exist in the distillation and road maintenance processes.

4. Problem Formulation

   The formulation of the problem contains questions related to the problems that will be raised in the research.

5. Literature Review

   Looking for references from other sources as information on conducting research. These sources can be from books, scientific journals, previous research, theses, and others.

6. Data Collection

   Collected data through questionnaires and distributed to 92 workers at PT XYZ, and conducted interviews with the Head of the SHE Department to get deeper insight.

7. Data Processing

   Data processing begins with problem identification. Next, a risk assessment is carried out using an assessment matrix to assess existing risks. Risk control is used to determine the various controls that already exist at PT XYZ. Furthermore, statistical analysis tests were carried out using SPSS to determine the effectiveness of existing risk controls on the number of work accidents.

8. Discussion and Analysis

   Interpret the results of data processing, which will then be compared with previous studies, and identify the main causal factors, the effectiveness of existing controls, and gaps between practices and safety standards.

9. Conclusion and Suggestion

   The results of the analysis that have been obtained are then summarized in the conclusion, while answering the formulation of the problem that has been designed before, and providing suggestions for everything that has been obtained during the research.

10. End

    Research has been completed, and the causes of decreased work accidents at PT. XYZ is eventually notified.

CHAPTER IV
DATA COLLECTION AND DATA PROCESSING

4.1 Data Collection

4.1.1 Respondents

This chapter presents the results of research that has been conducted at PT. XYZ related to "Risk Mitigation Highest Risk Level (Red Zone) Based on Hazard Identification Risk Assessment and Risk Control (HIRARC)". This research uses a quantitative approach with the method of distributing questionnaires to all workers as the research population. The questionnaire was distributed to all PT. XYZ workers with the aim of getting a comprehensive picture of the causes of the decline in the number of work accidents. From the total number of workers, 223 questionnaires were collected and could be used in the analysis. The following is the respondent data from this study:

Table 4. 1 PT. XYZ's Respondents

	ISI	SAMPLE	**%**
PT. XYZ	59	40	147,50%
Plant & SM	11	10	110,00%
SHE	3	1	300,00%
HRM & Engineering	32	24	133,33%
HCGS & FAT	3	1	300,00%
L&D	2	2	100,00%
HCD	8	2	400,00%

Table 4. 2 Sub-contract Respondents

	ISI	SAMPLE	%
Sub-Cont	164	52	315,38%
PT. SAM	20	17	117,65%
PT. AEA	14	5	280,00%
CV. SBY	5	3	166,67%
PT. PST	23	4	575,00%
MP	2	1	200,00%
PT. TMN	53	7	757,14%
PT. SPI	1	1	100,00%
PT. N	2	0	200,00%
PT. GDSK	19	6	316,67%
PT. UT	4	1	400,00%

	ISI	SAMPLE	%
PT. IMA	1	1	100,00%
PT. ERM	2	1	200,00%
PT. TRAC	2	2	100,00%
PT. BAGONG	9	1	900,00%
PT. BPSI	4	2	200,00%
PT. SSS	1	0	100,00%
KOPMA	2	1	200,00%

4.2 Data Processing

4.2.1 Identification of Hazard

Table 4. 3 Hazard Identification

No.	Activities	Code	Hazard	Risk
A1	Coal loading using loader	A1.1	Uneven front	Collapsed unit
		A1.2	Dusty or foggy environment	Operator is exposed to dust
		A1.3	Incompetent operator	Hitting or being hit by a unit
		A1.4	Flabby material	Collapsed unit
A2	Coal hauling using dump truck	A2.1	Incompetent operator	Hitting or being hit by a unit
		A2.2	Operator fatigue	Unit went off the track/hit the embankment
		A2.3	Operator performs unsafe actions while operating the unit	Crashed into another unit/hit the embankment
		A2.4	Unit trouble	Malfunction of the unit
		A2.5	Overload	Spilled materials
				Malfunction of the unit
		A2.6	Dusty or foggy environment	Crashed into another
				Operator is exposed to dust
		A2.7	Slippery road	Unit rolled over
		A2.8	Blind spot road	Unit crashed into embankment/off track
A3	Coal dumping	A3.1	Incompetent operator	Bumping into other units, coal spilled
		A3.2	Operator performs unsafe actions while operating the unit	Bumping into other units
		A3.3	Unit trouble	Unit on fire

No.	Activities	Code	Hazard	Risk
		A3.4	Dusty or foggy environment	Bumping into other units
				Operator is exposed to dust
		A3.5	Flabby work area	Collapsed unit
		A3.6	Sloped work area	Collapsed unit
A4	Road maintenance	A4.1	Operator does not know the repair area	Collapsed unit
		A4.2	Operator performs unsafe actions while operating the unit	Hit/collided by another unit, Collapsed unit
		A4.3	Unit trouble	Malfunction of the unit
		A4.4	Dusty or foggy environment	Operator is exposed to dust
A5	Road construction in landslide areas	A5.1	Operator does not know the area	Unit mired
		A5.2	Blind spot	Fallen on wood
		A5.3	Incompetent operator	Collapsed unit
		A5.4	Operator performs unsafe actions while operating the unit	Hit/collided by another unit, Collapsed unit
		A5.5	Unit trouble	Malfunction of the unit
		A5.6	Dusty/foggy environment	Operator exposure to dust/fog
		A5.7	Flabby work area	Collapsed unit
		A5.8	Sloped work area	Collapsed unit

4.2.2 Risk Assessment

Table 4. 4 Risk Assessment

No.	Activities	Code	Hazard	Risk	L	S	RL
A1	Coal loading using loader	A1.1	Uneven front	Collapsed unit	4	4	16
		A1.2	Dusty or foggy environment	Operator is exposed to dust	4	4	16
		A1.3	Incompetent operator	Hitting or being hit by a unit	3	4	12
		A1.4	Flabby material	Collapsed unit	3	4	12
A2	Coal hauling using dump truck	A2.1	Incompetent operator	Hitting or being hit by a unit	4	4	16
		A2.2	Operator fatigue	Unit went off the track/hit the embankment	4	4	16
		A2.3	Operator performs unsafe actions while operating the unit	Crashed into another unit/hit the embankment	4	4	16

No.	Activities	Code	Hazard	Risk	L	S	RL
		A2.4	Unit trouble	Malfunction of the unit	3	3	9
		A2.5	Overload	Spilled materials	4	4	16
				Malfunction of the unit	3	4	12
		A2.6	Dusty or foggy environment	Bumping into other units	4	4	16
				Operator is exposed to dust	4	4	16
		A2.7	Slippery road	Unit rolled over	5	4	20
		A2.8	Jalan blind spot	Unit crashed into embankment/off track	4	3	12
A3	Coal dumping	A3.1	Incompetent operator	Coal spilled	4	4	16
		A3.2	Operator performs unsafe actions while operating the unit	Bumping into other units	4	4	16
		A3.3	Unit trouble	Unit on fire	3	3	9
		A3.4	Dusty or foggy environment	Operator is exposed to dust	4	4	16
		A3.5	Flabby work area	Collapsed unit	4	4	16
		A3.6	Sloped work area	Collapsed unit	4	4	16
A4	Road maintenance	A4.1	Operator does not know the repair area	Collapsed unit	4	3	12
		A4.2	Operator performs unsafe actions while operating the unit	Hit/collided by another unit, Collapsed unit	4	4	16
		A4.3	Unit trouble	Malfunction of the unit	3	3	9
		A4.4	Dusty or foggy environment	Operator is exposed to dust	4	4	16
A5	Road construction in landslide areas	A5.1	Operator does not know the area	Unit mired	4	5	20
		A5.2	Blind spot	Fallen on wood	4	3	12
		A5.3	Incompetent operator	Collapsed unit	4	3	12
		A5.4	Operator performs unsafe actions while operating the unit	Hit/collided by another unit, Collapsed unit	4	4	16
		A5.5	Unit trouble	Malfunction of the unit	4	3	12

No.	Activities	Code	Hazard	Risk	L	S	RL
		A5.6	Dusty/foggy environment	Operator exposure to dust/fog	4	4	16
		A5.7	Flabby work area	Collapsed unit	4	4	16
		A5.8	Sloped work area	Collapsed unit	3	5	15

Table 4. 5 Risk Matrix

Likelihood	Severity				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)				A2.7	
Likely (4)			A2.8 A4.1 A5.2 A5.3 A5.5	A1.1 A1.2 A2.1 A2.2 A2.3 A2.5 A2.6 A3.1 A3.2 A3.4 A3.5 A4.2 A4.4 A5.4 A5.6 A5.7	A5.1
Possible (3)			A2.4 A2.5 A3.3 A4.3	A1.3 A1.4	A5.8
Unlikely (2)					
Rare (1)					

Based on the results of the occupational accident risk analysis according to the AS/NZS 4360:2004 standard that has been carried out, there are 30 risk variables, risk index values, and risk analysis matrix (level) that need to be considered as follows.

1. There are 21 risk variables classified as Very High, which means they have a very high risk potential.
2. It was found that there are 9 risk variables that are classified as High or have a fairly high risk.

3. There is 0 risk variable that are identified as Medium or have a medium level of risk.
4. There is 0 risk variable categorized as Low or has low potential.

4.2.3 Risk Control

Table 4. 6 Risk Control

No.	Activities	Code	Hazard	Risk	Risk Control
A1	Coal loading using loader	A1.1	Uneven front	Collapsed unit	SOP, planed Inspection
		A1.2	Dusty or foggy environment	Operator is exposed to dust	Using PPE (mask)
		A1.3	Incompetent operator	Hitting or being hit by a unit	Training, planned inspection
		A1.4	Flabby material	Collapsed unit	SOP, Workshop P5M, communication radio, sign installation
A2	Coal hauling using dump truck	A2.1	Incompetent operator	Hitting or being hit by a unit	Training, planned inspection
		A2.2	Operator fatigue	Unit went off the track/hit the embankment	Fatigue alarm, communication radio, DFIT validation, fatigue check, MCU
		A2.3	Operator performs unsafe actions while operating the unit	Crashed into another unit/hit the embankment	Induction, P5M, sign installation, communication radio, training K3LH, PPE, observation, speed gun, SIDAK, punishment
		A2.4	Unit trouble	Malfunction of the unit	Daily check mechanic, communication radio, PPE, observation, planned inspection, APAR
		A2.5	Overload	Spilled materials	Training K3LH, P5M, sign installation, observation, SIDAK
				Malfunction of the unit	

No.	Activities	Code	Hazard	Risk	Risk Control
		A2.6	Dusty or foggy environment	Bumping into other units Operator is exposed to dust	Watering the road using water truck, PPE (mask), if the fog is too thick then stop the operation
		A2.7	Slippery road	Unit rolled over	Stop operation, communication radio, planned inspections
		A2.8	Blind spot	Unit crashed into embankment/off track	Induction, P5M, sign installation, communication radio, PPE, observation, planned inspection
A3	Coal dumping	A3.1	Incompetent operator	Bumping into other units, coal spilled	Training, observation, SIDAK, punishment
		A3.2	Operator performs unsafe actions while operating the unit	Bumping into other units	Induction, training K3LH, safety talk, communication radio, PPE, observation, SIDAK, punishment
		A3.3	Unit trouble	Unit on fire	Daily check mechanic, P2H, communication radio, PPE, planed inspection
		A3.4	Dusty or foggy environment	Bumping into other units Operator is exposed to dust	Watering the road using water truck, PPE (mask), if the fog is too thick then stop the operation
		A3.5	Flabby work area	Collapsed unit	SOP, communication radio, sign installation
		A3.6	Sloped work area	Collapsed unit	SOP, communication radio, sign installation

No.	Activities	Code	Hazard	Risk	Risk Control
A4	Road maintenance	A4.1	Operator does not know the repair area	Collapsed unit	SOP, induction, re-induction, Workshop P5M, communication radio, PPE, observation
		A4.2	Operator performs unsafe actions while operating the unit	Hit/collided by another unit, Collapsed unit	Induction, training K3LH, safety talk, communication radio, PPE, observation, SIDAK, punishment
		A4.3	Unit trouble	Malfunction of the unit	Daily check mechanic, P2H, communication radio, PPE, planed inspection
		A4.4	Dusty or foggy environment	Operator is exposed to dust	Watering the road using water truck, PPE (mask), if the fog is too thick then stop the operation
A5	Road construction in landslide areas	A5.1	Operator does not know the area	Unit mired	SOP, induction, re-induction workshop P5M, communication radio, PPE, observation
		A5.2	Blind spot	Fallen on wood	SOP, induction, re-induction, training K3LH, safety talk, communication radio, PPE, observation
		A5.3	Incompetent operator	Collapsed unit	Training, observation, unscheduled inspection, punishment
		A5.4	Operator performs unsafe actions while operating the unit	Hit/collided by another unit, Collapsed unit	Induction, training K3LH, safety talk, communication radio, PPE, observation, SIDAK, punishment

No.	Activities	Code	Hazard	Risk	Risk Control
		A5.5	Unit trouble	Malfunction of the unit	SOP, Daily check mechanic, P2H, communication radio, PPE, planned inspection, APAR
		A5.6	Dusty/foggy environment	Operator exposure to dust/fog	PPE (mask), if the dust is too thick then stop operation, MCU
		A5.7	Flabby work area	Collapsed unit	SOP, communication radio, PPE, observation
		A5.8	Sloped work area	Collapsed unit	SOP, communication radio, PPE, observation

4.2 Statistical Analysis

a. Reliability test

Reliability test is a test to measure the extent to which a measurement instrument provides consistent and stable results if used repeatedly under the same conditions or at different times. Its function is to ensure that the data obtained from the instrument can be trusted, so that the research results become credible and are not influenced by irrelevant external factors.

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Table 4. 7 Cronbach's Alpha

Cronbach's Alpha	Category	Description
> 0.90	Very high reliability	Each item in it very consistently measures the same thing.

Cronbach's Alpha	Category	Description
0.70 – 0.90	High reliability	The items of the instrument are quite consistent, so the overall results can be trusted.
0.60 – 0.70	Medium/moderate reliability	The consistency is sufficient for initial use or exploratory research, but not as strong as the categories above it.
< 0.60	Low reliability	Items in the instrument do not show consistency so the results are less reliable.

- Reliability technology

Reliability Statistics

Cronbach's Alpha	N of Items
.774	5

The value of 0.774 is above the 0.70 threshold, so it can be categorized as “high” for the internal reliability of the instrument, consisting of 5 questions.

- Reliability system

Reliability Statistics

Cronbach's Alpha	N of Items
.750	6

The value of 0.750 also passes the threshold of 0.70, which, although slightly lower, still means high reliability.

b. The correlation between existing risk controls and work accidents

The correlation between risk control and work accidents was measured using Pearson's correlation. Pearson correlation helps to determine how closely and whether the improvement or effectiveness of risk control is statistically related to the reduction of work accidents.

- The result of the technology parameter

Table 4. 8 Technology Result

Correlations

		Radio	G_Track	D_Fit	System_Alert	Total
Radio	Pearson Correlation	1	.193**	.207**	.228**	.504**
	Sig. (2-tailed)		.004	.002	.001	.000
	N	223	223	223	223	223
G_Track	Pearson Correlation	.193**	1	.417**	.308**	.718**
	Sig. (2-tailed)	.004		.000	.000	.000
	N	223	223	223	223	223
D_Fit	Pearson Correlation	.207**	.417**	1	.433**	.791**
	Sig. (2-tailed)	.002	.000		.000	.000
	N	223	223	223	223	223
System_Alert	Pearson Correlation	.228**	.308**	.433**	1	.723**
	Sig. (2-tailed)	.001	.000	.000		.000
	N	223	223	223	223	223
Total	Pearson Correlation	.504**	.718**	.791**	.723**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	223	223	223	223	223

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the results of calculations using Pearson correlation, the highest score is D-fit with a value of 0.791. Then followed by System Alert with a value of 0.723, G-Track with a value of 0.718, and finally Radio communication with a value of 0.504.

- The result of the system parameter

Table 4. 9 System Result

Correlations

		P5M	SafetyTalk_CC	Supervisi	Sistem_Audit	Pemberian_Sanksi	Total
P5M	Pearson Correlation	1	.170*	.142*	-.009	.343**	.510**
	Sig. (2-tailed)		.011	.034	.897	.000	.000
	N	223	223	223	223	223	223
SafetyTalk_CC	Pearson Correlation	.170*	1	.479**	.229**	.436**	.728**
	Sig. (2-tailed)	.011		.000	.001	.000	.000
	N	223	223	223	223	223	223
Supervisi	Pearson Correlation	.142*	.479**	1	.140*	.683**	.690**
	Sig. (2-tailed)	.034	.000		.037	.000	.000
	N	223	223	223	223	223	223
Sistem_Audit	Pearson Correlation	-.009	.229**	.140*	1	.189**	.535**
	Sig. (2-tailed)	.897	.001	.037		.005	.000
	N	223	223	223	223	223	223
Pemberian_Sanksi	Pearson Correlation	.343**	.436**	.683**	.189**	1	.776**
	Sig. (2-tailed)	.000	.000	.000	.005		.000
	N	223	223	223	223	223	223
Total	Pearson Correlation	.510**	.728**	.690**	.535**	.776**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	
	N	223	223	223	223	223	223

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the results of calculations using Pearson correlation, the highest score is given for the category of giving punishment, with a value of 0.776. Then followed by the safety talk and coaching counseling with a value of 0.728, supervision with a value of 0.690, audit system with a value of 0.535, and finally P5M with a value of 0.510.

4.3 Fishbone Diagram of Highest Risk

After determining which risks are classified as very high level based on the matrix table above, the next step is to create a fishbone diagram of the two risks with the highest values. Based on the matrix table, risks with codes A2.7 and A5.1 have the highest values, with a risk level of 20.

4.3.1 Fishbone diagram of unit mired

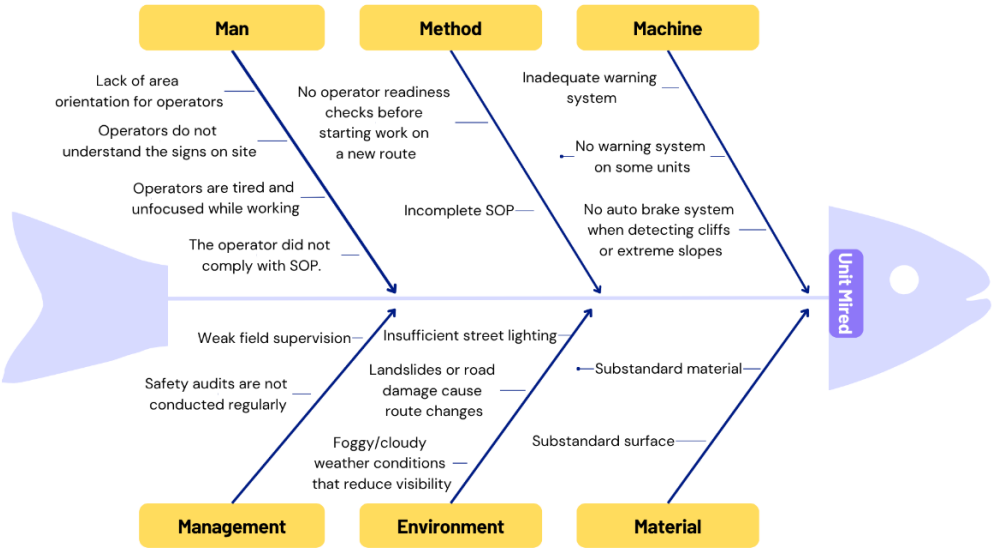


Figure 4. 1 Fishbone Diagram of Unit Mired

4.3.2 Fishbone diagram of unit rolled over

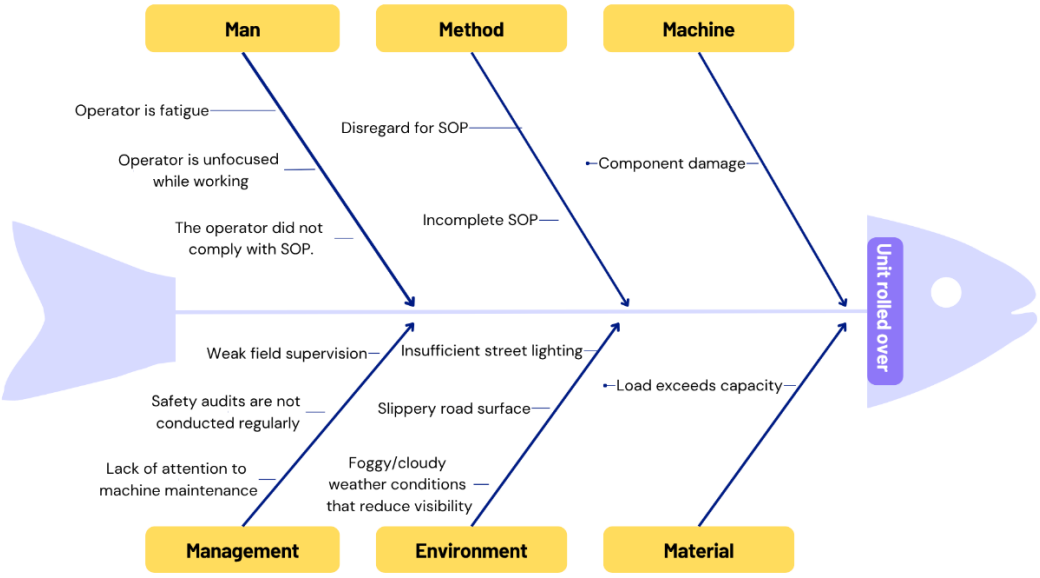


Figure 4. 2 Fishbone Diagram of Unit Rolled Over

CHAPTER V
DISCUSSION

5.1 HIRARC Discussion

5.1.1 Hazard Identification Discussion

At the hazard identification stage, a total of 30 hazard variables were obtained, spread across five main activities (A1–A5). From Table 4.3, it can be seen that coal transportation (A2) and road construction activities in landslide areas (A5) have the highest hazard code frequencies, indicating a higher risk complexity in both activities. For example, the dangers of "slippery roads" (A2.7) and "operators do not know the area" (A5.1) indicate the potential for accidents due to environmental factors and human error. This condition indicates the need for special attention to the aspects of operator training and management of working road conditions. Furthermore, hazards originating from dusty or foggy environments (A1.2, A2.6, A3.4, A4.4, A5.6) were also recorded throughout the activity, indicating that the air quality in the operating area played an important role in the potential for work accidents.

5.1.2 Risk Assessment

Based on Table 4.4 and the risk matrix (Table 4.5), 21 very high-risk variables (RL > 16) and 9 high-risk variables (RL 9–16) were found. The highest risk was noted on "slippery roads" (A2.7, RL = 20) and "operators not aware of the landslide area" (A5.1, RL = 20). This shows that the occurrence of accidents in the category of disasters (severity = 5) with high probability (likelihood = 4–5) is the main issue. This very high-level risk variable points to the need for prioritization of interventions. For example, to reduce the risk of the unit becoming intertwined due to slippery roads, it is necessary to apply a temporary stop operation procedure during slippery conditions (heavy rain/dust), as well as regular spraying of water. Meanwhile, the risk of "operators not knowing the landslide area" requires the mapping of landslide-prone zones and the implementation of re-induction for all operators before starting their duties in the area.

5.1.3 Risk Control

Table 4.6 describes the various risk controls that have been implemented, ranging from SOPs, planned inspections, training, to the use of PPE such as masks and radio communication. An example of effective control can be seen in the reduction of dust

exposure incidents, thanks to the use of masks and road watering. However, most controls are administrative (training, SOPs, induction) and depend on personnel compliance. The limitations of this administrative approach are seen in the danger of "incompetent operators" (A1.3, A2.1, A3.1, A5.3), where training without post-training validation can be less than optimal. Therefore, it is necessary to add direct audits in the field (safety walkdown) and accident simulations to measure the actual competence of operators. In addition, the punishment and incentive mechanisms can be strengthened to make the implementation of controls more consistent.

5.2 Correlation Between Risk Control with Work Accident

Pearson analysis is used to measure the relationship between the application of risk management (technological and system parameters) and the reduction in the incidence of work accidents. The correlation results show some key findings: The results of the reliability test showed that Cronbach's alpha value for the technology dimension was 0.774 and the system was 0.750, both of which were relatively high ($\alpha > 0.70$), so the questionnaire instrument could be considered consistent and valid for this study. This supports the belief that respondents' data reflects real perceptions of risk control and accident incidents. Furthermore, Pearson's correlation analysis revealed that the D-fit technology parameters ($r = 0.791$) and the punishment system ($r = 0.776$) had the highest positive correlation with a decrease in work accidents. This means that increasing the effectiveness of D-fit technology and the consistent application of sanctions are closely related to decreasing the number of accidents. Radio communication ($r = 0.504$) and P5M ($r = 0.510$) showed a moderate correlation, suggesting a potential complementary role. These findings confirm that a combination of strengthening technology and systemic policies is necessary for optimal outcomes.

5.3 Overall Analysis

In the entire series of analyses, starting from hazard identification to statistical analysis, the mine working environment, especially in coal transportation (A2) and landslide-prone road construction (A5), is the most critical source of risk. Of the 30 hazard variables, the highest frequency of slippery roads and operators do not understand the landslide zone underscores two main factors: the physical condition of the site (damaged asphalt, unexpected contours) and the element of human error due to a lack of understanding of

the work field. These two hazards then re-emerged as the highest risk (RL = 20), confirming the consistency between the frequency of occurrence and the magnitude of the potential impact of the accident. Furthermore, hazard variants related to air quality dust and fog were recorded evenly across all five activities (A1-A5). Although the severity of dust may be lower than that of slippery roads, its frequency and coverage suggest that, without technical controls (watering, ventilation) and PPE (quality masks), long-term exposure can reduce productivity and increase occupational health incidents.

5.4 Preventive Actions and Contingency Plans

A fishbone analysis helps identify the main causes of a risk. From the results, it is necessary to develop mitigation measures in two categories: preventive actions and contingency plans. Preventive actions aim to reduce the likelihood of a risk occurring, while contingency plans are prepared to respond if a risk does occur. The preventive mitigation approach ideally applies to the risk control hierarchy. This hierarchy includes elimination, substitution, engineering, administrative controls, and the use of PPE. In contrast, contingency plans formulate emergency procedures to limit negative impacts if risks arise.

5.4.1 Preventive actions and contingency plans of the unit mired

The following are the preventive actions and contingency plans of the unit mired that can be recap:

Table 5. 1 Preventive actions and contingency plans of the unit mired

Root causes		**Hierarchy Control**	**Preventive Action**	**Contingency Plan**
Man	- Operators are tired and unfocused. - No readiness check.	Administrative Control	- Structured break schedule. - Pre-start check-list form for route readiness for each shift. - Operator fatigue management training.	- If operator fatigue is detected, stop the shift. - Send a trained relief driver and perform a short handover
Method	- Incomplete SOP. - No operator readiness checks.	Administrative Control	- Revise & strengthen SOPs (include route &	If SOPs are not followed, then activate

Root causes		Hierarchy Control	Preventive Action	Contingency Plan
			tool verification steps). - SOP compliance audit at least monthly. - Repeated socialization through toolbox talks.	stop-work authority then conduct root-cause investigation and re-evaluate SOPs before operations resume.
Machine	- No auto-brake on extreme slopes. - Inadequate warning system.	Engineering Control	- Install an auto-brake system with tilt sensor. - Upgraded warning beacon and audible alarm for steep slopes.	If the vehicle approaches the cliff without control, then detach the load, apply manual brake, evacuate the operator via emergency exit.
Material	- Substandard surface. - Substandard material roadbed	Elimination and Substitution	- Road surface reconstruction (asphalt gradation according to specifications). - Replace sub-par material with grade A.	If the road collapses suddenly, install temporary patch (geotextile matrass + aggregate), mark the hazard, continue evacuation slowly.
Management	- Weak field supervision. - Safety audits are not conducted regularly.	Administrative Control	- Assign a field safety officer for each shift. - Schedule weekly OHS audits with a standardized checklist.	If weak oversight is identified then send an unannounced audit team, produce findings

Root causes		Hierarchy Control	Preventive Action	Contingency Plan
				report and quick corrective action.
Environment	- Insufficient streetlighting. - Landslides or road damage cause route changes. - Foggy/cloudy weather conditions that reduce visibility.	Engineering and Administrative Control	- Install T-prefab streetlights at critical points. - Install weather sensor and electronic warning board. - Slope stabilization (terracing).	If visibility < 30 m or landslide occurs then temporarily close route, divert to safe route, evacuate equipment and personnel.

5.4.2 Preventive actions and contingency plans of unit rolled over

The following is the preventive actions and contingency plans of unit mired that can be recap:

Table 5. 2 Preventive actions and contingency plans of unit rolled over

Root causes		Hierarchy Control	Preventive Action	Contingency Plan
Man	- The operator is unfocused and fatigued. - Operator did not comply with SOP.	Administrative Control	- Defensive driving retraining on uphill & slippery terrain. - Pre-shift mental check form for fatigue. - Reprimand and coaching if SOP is violated.	- If the operator looks tired in the field, then stop the unit in a safe place, call for a relief driver. - Conduct post-incident counseling after rolling over.
Method	- Disregard for SOP. - Incomplete SOP.	Administrative Control	- Complete SOP with details of load handling and maximum	If SOP is violated causing critical tilt, then activate safety

Root causes		Hierarchy Control	Preventive Action	Contingency Plan
			speed on inclines. - Simulate the SOP before work begins.	lock (watch / beacon), operator evacuation path from the cabin via escape hatch.
Machine	Component damage	Engineering Control	- Install tilt-sensor with interlock (motor shuts off if > 15°). - Strengthen manufacturer's suspension and counterweight for stability.	When a roll over starts to occur (sensor triggered) the interlock system automatically shuts down the engine, activates the SOS beacon and then the operator is evacuated by the rescue team.
Material	Load exceeds capacity	Substitution and Administrative Control	- Apply mandatory load-check before loading (tare and gross weight). - Load supervision by load master.	If overloading is detected, lower the load to capacity, move it to a spare unit until it is safe.
Management	- Weak field supervision. - Safety audits are not conducted regularly. - Lack of attention to machine maintenance.	Administrative Control	Routine maintenance schedule & checklist (suspension, brakes, steering).	If parts are found to be worn/damaged, stop operating the unit, order spare parts immediately and contact a specialized technician for repair.

Root causes		Hierarchy Control	Preventive Action	Contingency Plan
Environment	- Insufficient streetlighting. - Slippery road surface. - Foggy/cloudy weather conditions that reduce visibility.	Engineering Control and Administrative	- Add grip compound (sand) on slippery roads. - Weather sensor and slippery zone warning board. - Limit operation when visibility < 50 m.	If conditions are slippery/dark, direct the unit to a safe parking area, install road cones and portable lighting then follow up with drainage cleaning so that the surface is dry again.

5.5 Analysis of Inter-Action Conflicts

The following table summarizes the identification of conflicts between the primary countermeasures of the first risk and the second risk, as well as recommendations for adjustments so that each control can work in harmony without creating new hazards.

Table 5. 3 Analysis of Inter-Action Conflicts

Key Action (Unit Mired)	Potential Conflicts	Recommendation
Install autobrake on extreme slopes	Autobrake is able to brake suddenly when it detects a slope, which creates a risk of the unit losing momentum on an incline or stopping suddenly, which can trigger excessive tilting resulting in the unit rolling over.	- Set the autobrake with a gradual braking pattern (soft-engage). - Combine tilt sensor with manual override by trained operator. - Add tilt-sensor interlock in the unit.
Reconstruction of steep road edges (paving and guardrail)	Guardrails that are too rigid may pose additional risks. If the unit hits the guardrail at a low speed, the impact should not cause a serious accident. However, due to its rigidity, the guardrail does not absorb the impact energy well, so the impact force is reflected to the	- Use energy-absorbing guardrails (such as flexible steel rails) to absorb impact and prevent the unit from rolling over. - Add rumble strips a sufficient distance before the guardrail to provide early warning, allowing the operator

	vehicle. This may cause the unit to spin suddenly and eventually roll over.	to brake before reaching the edge.
Reroute to narrow winding road	Narrow roads plus steep inclines will create a high angle of inclination as the unit passes. This condition increases the risk of losing balance, making it easier for the unit to roll over, especially if the maneuver or load is unstable.	- Perform road leveling and widening at critical points to reduce gradients and provide safer movement for large units. - Limit maximum speed to below 10 km/h and use a pilot car in front of the unit to assist with navigation and ensure safe passage.
Improve street lighting with T-prefab lights	T-prefab lights installed at the edge of the road increase the load on the soil in the area. If the soil structure is not strong, subsidence or shifting of the soil around the lamp foundation may occur. As a result, the road surface becomes bumpy or uneven, creating slippery and unstable conditions that can trigger the unit to topple over.	- Move the position of the T-prefab lamp away from the road edge to reduce the load on the subsidence-prone soil. - Strengthen the lamp foundation using stable materials such as reinforced concrete or piles. - Perform soil compaction and use geotextiles before installation to increase the stability of the soil around the foundation. - Install warning signs such as “Uneven Surface” to alert operators when traveling in the area. - Conduct regular inspections and grading to ensure the road surface remains level, safe and does not pose a risk of overturning.

CHAPTER VI
CONCLUSION

6.1 Conclusion

Based on the results of identification, assessment, risk control, and statistical analysis using the HIRA method and fishbone diagram, the conclusions of this study are as follows:

1. From the results of the risk assessment using the HIRA method, 21 risk variables were obtained that were in the very high category (red zone). The two risks with the highest values include risk with code A2.7 (unit rolled over) and risk with code A5.1 (unit mired), each of which has the highest risk level value of 20. The assessment is carried out based on a combination of severity and likelihood scores calculated from observation and interview data.
2. After determining the two highest risks, a cause analysis was conducted using the fishbone diagram method. Next, a mitigation strategy was developed in two forms, including a preventive action and contingency plan. Preventive Action is structured based on the risk control hierarchy, starting from elimination, substitution, technical engineering, administrative control, to the use of personal protective equipment (PPE). Meanwhile, contingency plans are designed as anticipatory steps if the risk still occurs, including evacuation procedures, operational restrictions, and emergency response training. These mitigation actions aim to reduce the risk level so that it is no longer in the very high category and maintain the smooth and safe operation of the company.

6.2 Recommendation

Based on the conclusions that have been obtained, the recommendations that can be given to PT XYZ are as follows:

1. Prioritize addressing the main risks, for example, slippery roads and operator ignorance of landslide zones, as both have high impact and likelihood.
2. Prepare and rehearse emergency plans, such as evacuation and disaster response procedures, to deal with risks that persist despite mitigation.
3. Conduct periodic evaluations to ensure that risks are actually reduced and actions taken do not create new risks.

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