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Research Article

Application Failure Mode and Effect Analysis (FMEA) at Pt. Berau Coal Soft Material Excavation Activities

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ABSTRACT

Introduction: Geotechnical risks generally originate from geology, hydrology, technology and organization where these factors are interrelated. In coal mining businesses which are geologically associated with sedimentary materials such as sand or clay, swamp and mud materials, there are conditions where soft sedimentary materials need to be moved to obtain coal. This soft material is a material that has a low bearing capacity for the load placed on it so that the potential for failure is very likely to occur during excavation activities in this soft material.

Objectives: PT. Berau coal operates as a sole mining contractor and is one of the largest coal producers in Indonesia. The problems faced by the company are related to geotechnical risk management with the emergence of geotechnical problems including landslides of soft materials which result in accidents involving units and people, causing damage and death.

Methods: This research used the FMEA (Failure Mode and Effect Analysis) tool to assess the risk of failure in each process in soft material excavation activities and also used the 5W + 1H method to propose improvements to risk items that have a dominant RPN (Risk Priority Number) value.

Results: Based on the research results, it was found that 12 out of 17 failure items have dominant RPN values. Furthermore, the proposed improvements given using the 5W1H method are conducting routine maintenance, conducting an initial briefing before the activity takes place and checking the work area regularly.

Conclusions: The conclusion of this research is the problem on location research that caused landslides from soft materials which caused damage to units and deaths were identified and evaluated using the application of FMEA and 17 failure items were obtained including 12 failure items which became the risk matrix and recommendations for improvement were made using 5W + 1H.

Keywords: FMEA, Geotechnical, Risk Analysis, Risk Priority Number.

INTRODUCTION

A risk associated with an event can be defined as the opportunity for failure and the combination with the impacts that arise as a result of that failure (Heuberger, 2005). In the coal mining business, a mining company will face many risks ranging from geological, geotechnical, technological, economic, legal risks (*legal*), to political risks (Tidlund, 2021). Geotechnical risks generally originate from geology, hydrology, technology and organization where these factors are interrelated. In coal mining businesses which are geologically associated with sedimentary materials such as sand or clay, swamp and mud materials, there are conditions where soft sedimentary materials need to be moved to obtain coal. This soft material is a material that has a low bearing capacity for the load placed on it so that the potential for failure is very likely to occur during excavation activities in this soft material.

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The research location is at PT Berau Coal East Kalimantan and is a coal mining company. On location Research shows that accidents often occur in soft materials, namely landslides of soft materials which result in accidents involving units and people, causing damage to units and death. So it is necessary to evaluate geotechnical risk management in soft material excavation activities at PT. Berau Coal East Kalimantan using FMEA tools) to assess the risk of failure in each process in soft material excavation activities and can provide recommendations for appropriate improvements and prevention in handling them.

Risk analysis aims to predict undesirable circumstances, make decisions to control situations such as estimating potential damage and assessing effectiveness of control measures (Paithankar, 2011). This research uses the method (FMEA) to evaluate risk management performance in soft material excavation. FMEA is an approach or method for detecting or preventing problems in processes or products before the problem occurs (McDermott et al., 2008). FMEA is a tool used to record failures in the system by identifying the type of failure risk, the source and consequences of each failure, establishing procedures and carrying out appropriate repairs (Bouti and Kadi, 1994). The use of FMEA has been carried out since 1949 in the United States and has been widely adopted in various fields such as military, automotive, mechanics, aerospace industry, semi-conductor industry and many others (Sharma and Srivastava, 2018). The FMEA stages include identifying risks that have the potential for failure, determining the causes and effects of risks, determining priority risks or RPNs at several levels, namely severity, occurrence and failure detection (Liu et al., 2023).
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OBJECTIVES

Effective risk management requires the involvement of the entire project team and assistance from external experts knowledgeable in the field of risk management. In the risk management process, several things that are taken into consideration are technical issues, human elements and organizational issues (Institution of Civil Engineers et al., 2005). The risk management process, according to ISO 31000, should be a cyclical process including establishing context, risk identification, risk analysis, risk evaluation, risk management, communication and control, and monitoring and review. ISO 31000 provides principles and guidelines on risk management that can be applied in any industry or sector and used by any stakeholder, for example public/private and organizations/individuals. Because standards must be applicable to all situations and businesses, they are written in general terms. Consequently, the risk management process must be adapted to the project or business at hand (Charles et al., 2018).

FMEA is a systematic model used to find and prevent system problems, Dutra et al. (2024) explains that FMEA is used in the discussion process of company divisions to evaluate the causes of failure in process or product components and subsystems. FMEA type failure mode analysis allows anomalies to be assessed from a functional perspective in the structure where they occur by considering occurrence, detection and severity. This analysis allows the identification of individual failure modes of each anomaly, exploring the consequences of cause and effect (Fernandes et al., 2022). Over time, the FMEA method has been used in various fields such as automotive, medical, health, electronics, aerospace and other industries because it is considered to be applicable in all fields (Qin et al., 2020).

According to (Zeng et al., 2010) The stages in FMEA are determining the severity scale table, occurrence and detection capabilities, examining the aims, objectives and targets of a product/process; generally things identified through process flow diagrams, identifying potential process or product failures, identifying the impact of failures on components or process flows, operations, customers and government regulations, identifying potential root causes of potential failures, identifying first-level methods or procedures to detect product/process error detection/prevention, prevalence scores by estimating the frequency for potential causes of failure, detection ranking by looking at the probability that the process control will detect the root cause of a particular failure and RPN calculations by multiplying the three inputs.

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There are several levels in FMEA to determine RPN, namely the level of severity, occurrence and detection capability for each failure and then multiplying them. The severity level indicates how seriously an error or failure will affect things. The event rate is influenced by the frequency of errors or failures. Level of detection capability to identify potential errors or malfunctions (Wahyuni et al., 2024).

METHODS

This research uses primary data through verbal interactions such as interviews, as well as through surveys or questionnaires and secondary data from company risk documents. Data was collected based on participants' interpretations and perspectives. The data required is:

Data Collection

In this research, data collection was carried out through literature studies on existing risk management documents in the company, track records of identified risks and their control during the excavation and filling interview process. questionnaire semi-structured face-to-face meetings with 35 related employees.

Respondent Characteristics

The specific characteristics and characteristics of the expert group selected by the author meet the following criteria for respondents :

1. Working in a company engaged in mining services.
2. Minimum 3 (three) years experience in mining work.
3. Has a position in the company as part of the excavation planning (engineering) sector and the operations sector including (excavation, transportation and stockpiling).

Test Validity and Reliability

Testing this research uses the IBM SPSS 2022 application to ensure that instruments used can produce accurate results. Validity test is a test to explain how good the data collected from the research instrument is (Amalia et al., 2022). The validity test is used to measure the level of validity of a questionnaire used in a study (Bukoi et al., 2024). The correlation coefficient, which is used to assess the level of validity of a risk, will be obtained from the calculation results by means of If an item has a significant relationship with the total score, then the item is considered valid based on the correlation coefficient significance test, which has a significance level of 0.05. Instruments or question items are considered genuine if there is a substantial correlation between the items and the total score (r count > r table, two-sided test with a sig. value of 0.05) (Bukoi et al., 2024). Reliability testing measures how well an instrument produces stable and reliable readings. The Cronbach Alpha test is used to test the reliability of instruments with more than one correct response, such as questionnaires or essay-shaped instruments (Amalia et al., 2022). According to Taherdoost (2018) Coefficient Cronbach's Alpha is the most widely used reliability test. A good reliability test must have Cronbach's minimum alpha 0.6. Cronbach's alpha value indicates the reliability of the instrument; a value of less than 0.5 indicates low reliability, 0.5-0.7 indicates medium reliability, 0.7-0.9 indicates moderate reliability, 0.7-0.9 indicates high reliability, and >0.9 indicates very good reliability (Amalia et al., 2022; Bukoi et al., 2024).

Review and Identification of Potential Risk Classification Process Flow

Identify potential risks by knowing activities in extracting soft materials on location study. This research has a process flow consisting of the excavation planning process, excavation activities, transportation activities and stockpiling activities. Every activity has the potential risk of causing work accidents.

Risk Assessment Based on SOD (Severity, Occurrence, and Detection)

Determining the priority of a form of failure will involve a number of personnel, so personnel involved in implementing FMEA must first define the level of severity, probability of occurrence, and reliability of detection of

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each potential risk in soft material excavation activities. The following is a risk assessment classification based on SOD.

Severity is the value of the severity or effect caused by a failure mode. The rating scale given is 1 to 5 based on the percent level of severity.

Table 1. Occurrence

Occurrence (O)	
Score	Information
1	Rare (<10%)
2	Not Possible (10-25%)
3	Maybe (25-45%)
4	Possible (45-65%)
5	Almost Certain (65-90%)

Source : (Nasrallah et al., 2023)

Occurrence is the probability value of damage to the system. The rating scale given is 1 to 5.

Table 2. Severity

Severity (S)	
Score	Information
1	Not Significant
2	Small
3	Currently
4	Big
5	Great Disaster

Source : (Nasrallah et al., 2023)

Detection is the probability that damage to the system can be controlled. The rating scale given is 1 to 5.

Table 3. Detection

Detection (D)	
Score	Information
1	Almost Sure
2	High
3	Currently
4	Low
5	Remote

Source : (Nasrallah et al., 2023)

Ranking Highest RPN Value from SOD Results

RPN is a relative risk measurement. RPN is obtained from the product of the severity rating value, occurrence, and detection. The RPN can be determined before implementing improvement recommendations. RPN is used to assess the risk of knowing part Which one is the main priority based on the highest RPN value? The following is the formula for calculating the RPN value (Stamatis, 1995).

$$\mathbf{RPN = S \times O \times D}$$

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Information :
RPN = Risk Priority Number
S = Severity
O = Occurrence
D = Detection
Determination of the RPN value using the Nasrallah classification, 2023 which is categorized into various levels of value 1-5 means the score scale SxOxD in multiples of 5, which means the data range of RPN values is from 1 to 125 or 5x5x5 = 125 which is then depicted in the risk matrix (Table 4). Each level is a green label with an RPN value between 5 – 15 which means it is acceptable, a yellow label with an RPN value of 15 – 30 which means it needs to be programmed, an orange label with an RPN value of 30 – 75 which means quick repairs are needed, a red label with an RPN value of 75 – 125 which means emergency repairs are needed. (Nasrallah et al., 2023).

Table 4. Risk Matrix

S X O X D	1	2	3	4	5
5	5	10	15	20	25
10	10	20	30	40	50
15	15	30	45	60	75
20	20	40	60	80	100
25	25	50	75	100	125

Source : (Nasrallah et al., 2023)

Analysis of Improvement Recommendations
After obtaining the RPN value, ranking This is done by looking at the highest RPN value and then making improvement proposals using the 5W + 1H formula improvement recommendation analysis using the Kaizen principle, which is the principle of continuous, focused and structured improvement. (Tri et al., 2019). This stage is the implementation of the kaizen principle. The kaizen principle is the principle of continuous, focused and structured improvement (Tri et al., 2019). This stage is carried out by means of interviews and direct observations on the production floor after knowing the factors causing the prioritized problems. After conducting interviews and direct observations, analysis was then carried out and a table of proposed improvements was made using the 5W+1H method

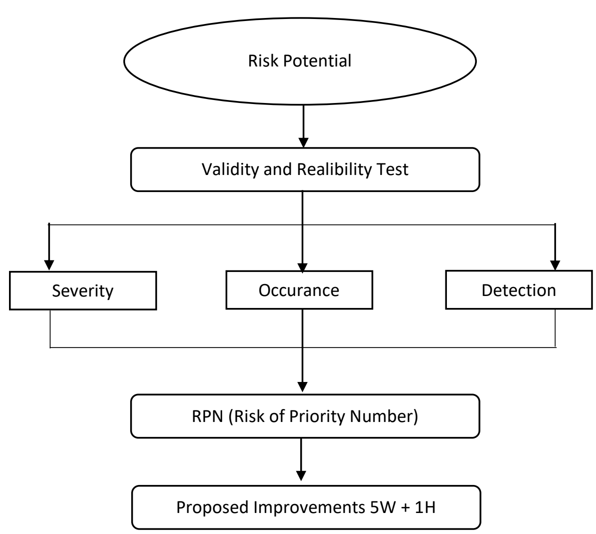

Figure 1. Research Process Flow Diagram

The flow diagram depicts the flow of potential risk analysis activities that occur at PT Berau Coal based on actual events at the research location.

RESULTS

Flow of PT Berau Coal's soft material excavation activities

PT Berau Coal has a procedure for extracting soft materials. This activity procedure consists of 4 activities, namely excavation and transportation planning activities, excavation activities, transportation activities and stockpiling activities. Figure 2 shows the flow of the soft material excavation process.

Figure 2. Soft Material Excavation Process Flow of PT. Berau Coal, East Kalimantan

Excavation and transportation planning activities are carried out by designing slopes on soft materials, preparing work areas, personnel and equipment, preparing initial loading, layering, further loading for excavation, preparing formation activities consisting of forming slope designs, making subdrain and *counterweight,* preparing post-excavation and formation designs consisting of finished designs, standby breakdown, breaks, overshit and holidays. Excavation and formation activities were carried out on the first and second layers based on the initial design. Soft material transportation activities refer to mining road management procedures and soft material stockpiling activities refer to stockpiling procedures in the disposal area.

Validity and Reliability Test

In this research, the significance level used is 5%, namely 0.344. This value is based on the r value of the moment product. The calculated r value is taken from the results of the validity test. Mark r table then contrasted with the results r count. Because each question has a value of rcount > rtable. Meanwhile, a good reliability test must have Cronbach's minimum alpha 0.6. is the result of the validity test and reliability from severity, occurrence and detection:

Table 5 Validity Test Results and Reliability Severity, Occurrence, and Detection

Work Process Flow	Code	Failure	r-table	Validity			Reliability			Results
				Severity	Occurrence	Detection	Severity	Occurrence	Detection	
Planning	R1	The soft material geology model does not match the actual	0.334	0.38545	0.432037	0.498936	0.829	0.735	0.797	Valid and Reliable
	R2	Plans and technical studies do not correspond to actual mine conditions	0.334	0.54713	0.42295	0.44509	0.812	0.73	0.801	Valid and Reliable
Excavation and Formation of slope design	R3	Do not do briefing work plan before work	0.334	0.49288	0.40765	0.464482	0.815	0.732	0.799	Valid and Reliable
	R4	There are units/humans within the unit's maneuver radius	0.334	0.64973	0.459533	0.413138	0.805	0.735	0.801	Valid and Reliable
	R5	There is a crack in the front loading area	0.334	0.56114	0.58272	0.379573	0.811	0.717	0.805	Valid and Reliable

Work Process Flow	Code	Failure	r-table	Validity			Reliability			Results
				Severity	Occurrence	Detection	Severity	Occurrence	Detection	
	R6	There is saturated material in the front loading area	0.334	0.46774	0.414714	0.587168	0.816	0.731	0.791	Valid and Reliable
	R7	There are units/humans within the insecure radius of the high slope	0.334	0.47657	0.545501	0.400626	0.817	0.719	0.803	Valid and Reliable
	R8	There is activity humans within an unsafe radius at the crest of the excavation wall	0.334	0.39256	0.447385	0.505851	0.831	0.734	0.797	Valid and Reliable
	R9	The height of the slope does not match the height of the dig-loader cab in the procedure	0.334	0.66326	0.56316	0.677988	0.805	0.723	0.783	Valid and Reliable
	R10	Not available counterweight in the area at the foot of the critical excavation wall	0.334	0.35567	0.359615	0.572107	0.822	0.734	0.792	Valid and Reliable
	R11	There is an overhang, material hanging and undercut in the excavation wall	0.334	0.40746	0.375261	0.602768	0.82	0.742	0.79	Valid and Reliable
	R12	The slope of the excavation wall was not formed according to technical studies	0.334	0.76278	0.378635	0.359743	0.794	0.735	0.804	Valid and Reliable
	R13	Supervisors do not supervise activities excavation and forming slope designs	0.334	0.46812	0.485878	0.346215	0.816	0.725	0.809	Valid and Reliable
Hauling	R14	There are non-standard road conditions (superelevation, road grade, and road width)	0.334	0.53608	0.538544	0.582006	0.812	0.721	0.791	Valid and Reliable
	R15	There are critical road conditions (puddles of water, mud deposits, swamps and height differences on	0.334	0.69625	0.43407	0.419873	0.802	0.739	0.806	Valid and Reliable

Work Process Flow	Code	Failure	r-table	Validity			Reliability			Results
				Severity	Occurrence	Detection	Severity	Occurrence	Detection	
		either side of the road)								
Dumping	R16	There are units/humans within the unit's maneuver radius	0.334	0.35284	0.406847	0.764331	0.825	0.732	0.776	Valid and Reliable
	R17	There are no stockpiling limits	0.334	0.69968	0.61186	0.344613	0.803	0.716	0.807	Valid and Reliable

Identify Potential Risks Using FMEA

FMEA is an analytical tool for identifying and assessing potential failures in processes or products which are classified into three levels, namely severity level, failure level and detection level (Dutra et al., 2024; Fernandes et al., 2022; Nasrallah et al., 2023; Wahyuni et al., 2024; Zeng et al., 2010). Before carrying out an FMEA assessment, identify risks in the soft material excavation process at PT. Berau Coal in East Kalimantan was carried out through observations and distributing questionnaires to the company. After data collection, there are 4 processes for extracting PT soft materials. Berau Coal East Kalimantan which consists of planning (Preparation), excavation and formation, transportation and stockpiling and several confirmed risk items have been identified as many as 17 items (Table 5) from 4 soft material excavation process flows.

Table 5 Identification of failures from PT's soft material excavation process. Berau Coal

Work Process Flow	Code	Failure	Reason	Effect
Planning	**R1**	The soft material geology model does not match the actual	no detailed soft material geology model is available	the work plan made does not match the geometry of the soft material
Planning	**R2**	Plans and technical studies do not correspond to actual mine conditions	person in charge does not verify actual field conditions before making plans	the work plans made are not in accordance with actual progress excavation
Excavation and Formation of slope design	**R3**	Do not do briefing work plan before work	the supervisor was in a hurry and did not gather the workers together briefing work plan	workers do not know the latest information in their work area
Excavation and Formation of slope design	**R4**	There are units/humans within the unit's maneuver radius	initiative employees for activity on the unit's maneuvering radius	units/people have the potential to be hit or knocked over by operating units
Excavation and Formation of slope design	**R5**	There is a crack in the front loading area	The bearing capacity of cracked material is unable to support the load above it	front wall landslides, and subsidence on the front loading pad

Work Process Flow	Code	Failure	Reason	Effect
Excavation and Formation of slope design	**R6**	There is saturated material in the front loading area	The original soft material is not layered and has a clear geometry trap air in the area front loading	the unit collapsed in the front loading pad area, water infiltration in the slope area thus triggering instability
Excavation and Formation of slope design	**R7**	There are units/humans within the insecure radius of the high slope	initiative employees for activity unsafe area	humans were hit by landslide material
Excavation and Formation of slope design	**R8**	There is activity humans within an unsafe radius at the crest of the excavation wall	initiative employees for activity unsafe area	people crushed by landslide material
Excavation and Formation of slope design	**R9**	The height of the slope does not match the height of the dig-loader cab in the procedure	operator excavator and supervisors do not ensure the loading process refers to the required slope height	landslide on the front wall
Excavation and Formation of slope design	**R10**	Not available counterweight in the area at the foot of the critical excavation wall	supervisor is not identify critical condition of the foot of the excavation wall	landslide on the front wall
Excavation and Formation of slope design	**R11**	There is an overhang, material hanging and undercut in the excavation wall	operator excavator and the supervisor does not confirm the material hanging or overhang position when loading on the front wall	landslide on the front wall
Excavation and Formation of slope design	**R12**	The slope of the excavation wall was not formed according to technical studies	operator excavator and supervisors do not ensure the loading process by forming slopes according to requirements	landslide on the front wall
Excavation and Formation of slope design	**R13**	Supervisors do not supervise activities excavation and forming slope designs	supervisors are distracted by other activities	work progress and dynamic hazards in the work area are not identified and controlled
Hauling	**R14**	There are non-standard road conditions (superelevation, road grade, and road width)	Mine road repairs are not carried out continuously according to the work plan	units collapsed, units fell and units hit embankments
Hauling	**R15**	There are critical road conditions (puddles of water, mud deposits, swamps and height differences on either side of the road)	control of critical road conditions is not carried out	units collapsed, units fell and units hit embankments
Dumping	**R16**	There are units/humans within the unit's maneuver radius	initiative employees for activity on the unit's maneuvering radius	units/people have the potential to be hit or knocked

Work Process Flow	Code	Failure	Reason	Effect
				over by operating units
Dumping	**R17**	There are no stockpiling limits	operator dozer and supervisors do not ensure the availability of stockpiling limit benchmarks	the unit collapsed and collapsed Because there is no reference to hoarding

After the risk items are identified, the level of severity, failure and detection is then assessed by collecting the results of the questionnaire data which is processed using Microsoft Excel. The RPN calculation stage begins by adding up each level of risk assessment, namely severity, failure and detection (Adriant, 2018). Next, to get the average value for each level of risk assessment, the total results were divided based on the number of respondents received, namely 35 respondents (attachment 1). After the average value is obtained, the calculation is carried out using a formula **SxOxD** to get the RPN value (Table 6).

Table 6. FMEA assessment of PT's soft material excavation process. Berau Coal

Work Process Flow	Code	Failure	S	THE	D	RPN
Planning	R1	The soft material geology model does not match the actual	4	3	5	60
Planning	R2	Plans and technical studies do not correspond to actual mine conditions	4	4	2	34
Excavation and Formation of slope design	R3	Do not do briefing work plan before work	4	2	3	23
Excavation and Formation of slope design	R4	There are units/humans within the unit's maneuver radius	4	2	3	23
Excavation and Formation of slope design	R5	There is a crack in the front loading area	4	2	3	22
Excavation and Formation of slope design	R6	There is saturated material in the front loading area	4	3	4	45
Excavation and Formation of slope design	R7	There are units/humans within the insecure radius of the high slope	4	2	4	30
Excavation and Formation of slope design	R8	There is activity humans within an unsafe radius at the crest of the excavation wall	4	3	4	42
Excavation and Formation of slope design	R9	The height of the slope does not match the height of the dig-loader cab in the procedure	5	2	2	18
Excavation and Formation of slope design	R10	Not available counterweight in the area at the foot of the critical excavation wall	4	4	4	71
Excavation and Formation of slope design	R11	There is an overhang, material hanging and undercut in the excavation wall	5	4	2	38

Work Process Flow	Code	Failure	S	THE	D	RPN
Excavation and Formation of slope design	R12	The slope of the excavation wall was not formed according to technical studies	4	4	4	51
Excavation and Formation of slope design	R13	Supervisors do not supervise activities excavation and forming slope designs	4	4	3	39
Hauling	R14	There are non-standard road conditions (superelevation, road grade, and road width)	5	2	4	36
Hauling	R15	There are critical road conditions (puddles of water, mud deposits, swamps and height differences on either side of the road)	5	3	4	54
Dumping	R16	There are units/humans within the unit's maneuver radius	3	3	3	31
Dumping	R17	There are no stockpiling limits	5	3	3	35

After the FMEA calculation is carried out using the multiplication formula SxOxD = RPN. Next, a ranking of the highest RPN values is carried out based on *Risk Matrix* as a reference for assessing the level of RPN (Table 4). Based on these calculations, 5 failure modes have been obtained which have RPN values in the range of 15-30 and are colored yellow, 12 risk factors have high RPN values with a value range between 30-75 and are colored. *orange* (Table 7).

Table 7. FMEA calculation results with the highest RPN values

Work Process Flow	Code	Failure	S	THE	D	RPN
Planning	R1	The soft material geology model does not match the actual	4	3	5	60
	R2	Plans and technical studies do not correspond to actual mine conditions	4	4	2	34
	R6	There is saturated material in the front loading area	4	3	4	45
	R8	There is activity humans within an unsafe radius at the crest of the excavation wall	4	3	4	42

Work Process Flow	Code	Failure	S	THE	D	RPN
	R10	Not available counterweight in the area at the foot of the critical excavation wall	4	4	4	71
	R11	There is an overhang, material hanging and undercut in the excavation wall	5	4	2	38
	R12	The slope of the excavation wall was not formed according to technical studies	4	4	4	51
	R13	Supervisors do not supervise activities excavation and forming slope designs	4	4	3	39
Hauling	R14	There are non-standard road conditions (superelevation, road grade, and road width)	5	2	4	36
	R15	There are critical road conditions (puddles of water, mud deposits, swamps and height differences on either side of the road)	5	3	4	54
Dumping	R16	There are units/humans within the unit's maneuver radius	3	3	3	31
	R17	There are no stockpiling limits	5	3	3	35

Based on table 7, the results of FMEA calculations have obtained RPN values with the highest values, namely in 3 process flows including planning/preparation, excavation and slope design formation, and embankment with 12 of 17 risk factors that have the potential to fail and need to be repaired to minimize problems that will occur in the future. The kaizen approach (5W+1H) is used to organize improvement stages. After knowing all the causes, then carry out the improvement stages using what, why, where, when, who, and how. Therefore, the next step is to provide suggestions for improvements using the 5W+1H method for the 8 most potential risk factors (table 8)(Jia et al., 2024; Krisnaningsih et al., 2021).

Table 8. Proposed improvements based on 5W + 1H

Work Process Flow	Code	Item Risk	RPN	What (What is the improvement plan?)	Why (Why does it need to be repaired?)	Who (Who did?)	Where (Where is the repair location?)	When (When is the repair time?)	How (What are the repair steps?)
Planning	**R1**	The soft material geology model does not match the actual	60	updating the geological model by taking actual data	so that the work plan meets the conditions actual can be appropriate	Geology Supervisor	At the boundary of soft material	when making plans before work begins	geology supervisor coordinate with the mine plan boundary, plan the work area and then detail the geometry of the soft material
Planning	**R2**	Plans and technical studies do not correspond to actual mine conditions	34	person in charge checks actual conditions around soft material boundary area	so that work plans can be precise according to actual conditions in the field	Mine Plan, Supervisor Mining & Supervisor Geoteknik	At the boundary of soft material	when making plans before work begins	The person in charge is immediately available and checks suitability plan work that will be made according to actual conditions
Excavation and Formation of slope design	**R6**	There is saturated material in the front loading area	45	the supervisor instructed the dozer unit to layer saturated material	prevents the unit from collapsing and collapsing	Supervisor Direct	Front Loading	shortly after saturated material conditions are found	supervisor requests a hauler unit with a load of hard material dumped at the location of saturated material, then the hauler unit performs a fire
Excavation and Formation of slope design	**R8**	There is activity humans within an unsafe radius at the crest of the excavation wall	42	do briefing return to all employees to not activity in the excavation crest area	prevent humans from being scoured by landslide material	Supervisor Direct	Front Loading	shortly after humans were found in the excavation crest	the supervisor immediately stopped the operation, then continued briefing to all employees who activity of front loading area
Excavation and Formation of slope design	**R10**	There is no counterweight in the foot area of the critical excavation wall	71	the supervisor instructs the dozer unit to form the counterweight	strengthen the bearing capacity of the foot of the excavation wall	Supervisor Direct	Front Loading	before activity excavation started	supervisor requests a hauler unit with a load of hard materials dumped in the formation area counterweight, then the hauler unit does the hearth
Excavation and Formation of slope design	**R11**	There is an overhang, material hanging and undercut in the excavation wall	38	carry out sloping of excavation walls (undercut & material hanging), layering of the dig-load unit seat (overhang)	ensure there is no potential for landslides on the excavation walls	Supervisor Directly, Geotechnical and Mine Plan Supervisor	Front Loading	shortly after the discovery of the material hanging, overhang & undercut	direct supervisor instruct unit support excavator and dozers to do excavation wall fireplaces
Excavation and Formation of slope design	**R12**	the slope of the excavation wall was not formed according to technical studies	51	carry out sloping of excavation walls (undercut & material hanging), layering of the dig-load unit seat (overhang)	make sure there aren't any material which has the potential to fall is on the excavation wall	Supervisor Direct, Supervisor, Geotechnical and Mine Plan Supervisor	Front Loading	shortly after the discovery of the overhang & undercut excavation wall	direct supervisor instruct unit support excavator and dozers to do excavation wall fireplaces

Work Process Flow	Code	Item Risk	RPN	What (What is the improvement plan?)	Why (Why does it need to be repaired?)	Who (Who did?)	Where (Where is the repair location?)	When (When is the repair time?)	How (What are the repair steps?)
Excavation and Formation of slope design	**R13**	Supervisors do not supervise activities excavation and forming slope designs	39	mining supervisor does briefing Return to direct supervisor	ensure supervisors focus on monitoring the front loading area	Supervisor Mining	Front Loading	shortly after being discovered	the mining supervisor calls the supervisor directly then briefing direct supervisory duties
Hauling	**R14**	There are non-standard road conditions (superelevation, road grade, and road width)	36	standardize mining roads according to requirements	ensure the mine road is always in standard condition	Supervisor Mining	Mine Road	shortly after being discovered	supervisor mining coordinate road repairs with direct supervision
Hauling	**R15**	There are critical road conditions (puddles of water, mud deposits, swamps and height differences on either side of the road)	54	standardize mining roads according to requirements	ensure the mine road is always in standard condition	Supervisor Mining	Mine Road	shortly after being discovered	supervisor mining coordinate road repairs with direct supervision
Dumping	**R16**	There are units/humans within the unit's maneuver radius	31	do briefing return to all employees to not activity in the area of the unit's maneuvering radius	prevent units or people from being knocked over or hit by operating units	Supervisor Direct	Disposal	shortly after being discovered	the supervisor immediately stopped the operation, then continued briefing to all employees who activity of front loading area
Dumping	**R17**	There are no stockpiling limits	35	provide dumping limit benchmarks and update them according to disposal progress	prevent dumping of hauler units in position not safe	Supervisor Direct	Disposal	shortly after being discovered	the supervisor immediately installs or renew popular law dumping

Based on the results of the proposed improvements in table 7, the proposed improvements were analyzed using direct observation at the research site, conducting interviews with related staff and collecting data through questionnaires, for example the head of engineering and the head of operations who provided information and suggestions and improvements for all processes in soft material excavation planning. Carrying out and arranging routine preventive maintenance activities for each tool and machine so that the existing tools or machines do not lose their specified Lifetime, reshaping materials and checking drainage in crack/subsidence areas, conducting initial shift briefings, check the support unit to ready status, make improvements to work area information attributes, Distributing loading plan information, check the conformity of the work area with the plan and immediately make adjustments, carry out sloping/reshaping material on the excavation walls, do coordination hard material supply the area blending material.

DISCUSSION

PT Berau Coal identifies potential risks based on problems on location research, namely that there was an avalanche of soft material which resulted in an accident involving units and people, causing damage to the unit and death. So it is necessary to evaluate geotechnical risk management in soft material excavation activities using the FMEA method. The results of the potential risk analysis found 17 failures and of them there were 12 failures, namely potential cracks/subsidence, workers not carrying out initial shift briefings, lack of tools for actual excavation, lack of work area information attributes, not distributing loading plan information, mismatch in excavation flow and formation design with work plans and geotechnical recommendations, the excavation walls contain overhang/hanging and undercut, and there is a ratio blending unsuitable material which has a high RPN value based on the risk matrix, this value shows an orange color which means quick repairs are needed, therefore the proposed repair is carried out using 5W + 1H which shows routine maintenance behavior, conducting an initial briefing before the activity takes place and checking the work area.

REFERENCES

[1]. R. Heuberger, “Risk analysis in the mining industry,” *e SAIMM Proceedings of The management of risk in the Minerals Industry*, 2005, [Online]. Available: https://journals.co.za/doi/pdf/10.10520/AJA0038223X_3048

[2]. M. Tidlund, *Geotechnical risk management using the observational method*. Stockholm: KTH Royal Institute of Technology, 2021.

[3]. A. Paithankar, “HAZARD IDENTIFICATION AND RISK ANALYSIS IN MINING INDUSTRY,” National Institute of Technology, Rourkela, 2011. [Online]. Available: http://ethesis.nitrkl.ac.in/2445/1/Amol_thesis_final.pdf

[4]. R. E. McDermott, R. J. Mikulak, and M. R. Beauregard, *The Basics of FMEA*, 2nd ed. CRC Press, 2008.

[5]. A. Bouti and D. A. Kadi, “A STATE-OF-THE-ART REVIEW OF FMEA/FMECA,” *Int. J.Rel. Quality. Saf. Eng.*, vol. 01, no. 04, pp. 515–543, Dec. 1994, doi: 10.1142/S0218539394000362.

[6]. K. D. Sharma and S. Srivastava, “Failure Mode and Effect Analysis (FMEA) Implementation: A Literature Review,” *JoARASS*, vol. 5, no. 1–2, pp. 1–17, 2018.

[7]. H. Liu, R. Ma, G. He, A. Lamrabet, and S. Fu, “The impact of blockchain technology on the online purchase behavior of green agricultural products,” *Journal of Retailing and Consumer Services*, flight. 74, p. 103387, Sep. 2023, doi: 10.1016/j.jretconser.2023.103387.

[8]. Institution of Civil Engineers, Faculty of Actuaries, and Institute of Actuaries, Eds., *RAMP - risk analysis and management for projects: a strategic framework for managing project risk and its financial implications*, 2. ed. London: Thomas Telford, 2005.

[9]. P. Dutra, S. Teixeira, C. Wajdowicz, and J. Duarte, “Modified FMEA for risk management in geotechnical structures during hydraulic circuit filling of a hydroelectric power plant,” *S&R*, vol. 47, no. 1, p. e2024014422, Jan. 2024, doi: 10.28927/SR.2024.014422.

[10]. I. Nasrallah *et al.*, “Evaluating the academic scientific laboratories’ safety by applying failure mode and effect analysis (FMEA) at the public university in Lebanon,” *Helion*, vol. 9, no. 12, p. e21145, Dec. 2023, doi: 10.1016/j.helion.2023.e21145.

[11]. D.H. Stamatis, *Failure mode and effect analysis: FMEA from theory to execution*. Milwaukee, Wisc: ASQC Quality Press, 1995.

[12]. D. Tri, A. Rakhmanita, and Anggriani, "Implementation of Kaizen in Improving Performance (Case Study of Manufacturing Companies in Tangerang)," *Ecodemica*, vol. 3, no. 2, [Online]. Available: http://ejournal.bsi.ac.id/ejurnal/index.php/ecodemica

[13]. R. Fernandes, A. C. Sieira, and A. Menezes Filho, “Methodology for risk management in dams from the event tree and FMEA analysis,” *S&R*, vol. 45, no. 3, pp. 1–15, Aug. 2022, doi: 10.28927/SR.2022.070221.

[14]. H. C. Wahyuni, M. A. Rosid, R. Azara, and A. Voak, “Blockchain technology design based on food safety and halal risk analysis in the beef supply chain with FMEA-FTA,” *Journal of Engineering Research*, p. S2307187724000294, Feb. 2024, doi: 10.1016/j.jer.2024.02.002.

[15]. S. X. Zeng, C. M. Tam, and V. W. Y. Tam, “Integrating Safety, Environmental and Quality Risks for Project Management Using a FMEA Method,” *ECONOMICS OF ENGINEERING DECISIONS*, vol. 21, no. 1, pp. 44–52, 2010.

[16]. I. Adriant, “APPLICATION OF THE FAILURE MODE AND EFFECT ANALYSIS (FMEA) METHOD AND EXPERT SYSTEM DESIGN IN THE GULOMANTUNG WAREHOUSE OF PT. SEMEN INDONESIA LOGISTICS," *Journal of Logistics and Transportation Management*, vol. 4, no. 2, 2018.
[17]. F. Jia, G. Shahzadi, M. Bourlakis, and A. John, “Promoting resilient and sustainable food systems: A systematic literature review on short food supply chains,” *Journal of Cleaner Production*, vol. 435, p. 140364, Jan. 2024, doi: 10.1016/j.jclepro.2023.140364.
[18]. E. Krisnaningsih, P. Gautama, and M. F. K. Syams, "QUALITY IMPROVEMENT PROPOSAL USING FTA AND FMEA METHODS," *InTent*, vol. 4, no. 1, 2021.