



Strategic Decision Analysis in Mine Planning to Achieve Coal Production Target due to Mud Accumulation: A Case Study at Pit Garuda, PT Bara Nusantara Energi

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ABSTRACT

Coal remains a vital energy resource worldwide, particularly in developing countries, due to its affordability, wide availability, and essential role in meeting growing electricity and industrial demands. This study aims to develop strategic decisions in mine planning to achieve coal production targets despite the challenges posed by mud accumulation at Pit Garuda, PT Bara Nusantara Energi (BNE). This mud, which has accumulated over several periods and now totals 981,254 m³ at Pit Garuda area as of June 2024, causes the coal area to be submerged, so the coal-getting process cannot be carried out. The method used in this research is the Kepner-Tregoe approach, which consists of four stages: Situation Appraisal (SA), Problem Analysis (PA) using the Fishbone Diagram, Decision Analysis (DA) with a Simple Multi-Attribute Rating Technique (SMART) method, and Potential Problem Analysis (PPA) to anticipate implementation risks. Data were collected through interviews, Focus Group Discussions, questionnaires, and secondary data from operational reports and company technical documents. Three alternatives for handling mud were evaluated: conventional loading, slurry pump to void, and slurry pump with geotube. These alternatives were analyzed using SMART based on six score attributes: preparation, additional treatment, productivity, availability of storage, safety, and environment. The results showed that the slurry pump-to-void method is the most efficient solution. Although it has the highest cost (112.32 billion rupiah), it also achieved the highest overall score (61.17 points). This method is considered effective for quickly overcoming operational challenges and aims to process 2,289,592 m³ of mud within 3.5 months. The study recommends immediately adopting the slurry pump to void alternative, supported by intensive supervision and a well-planned risk management strategy. This approach will help ensure smooth production and prevent potential issues, such as insufficient mud storage capacity, inefficient pumping, depletion of mud before the project is finished, and delays in the arrival of pumping units.

Keywords: Coal Production, Mud Management, Mining, Kepner-Tregoe, SMART Analysis, Fishbone Diagram.

INTRODUCTION

As a fossil fuel that has been used for several centuries, coal is important in meeting global energy needs, especially in power generation and manufacturing industries. Global coal consumption in 2023 will account for 26% of total energy resources (MSCI Institute, 2024). In Indonesia, coal production achievements have continued to increase since 2020. Based on data

from the Directorate General of Mineral and Coal of the Ministry of Energy and Mineral Resources (ESDM), coal production in 2020 amounted to 564 million tons and in 2023 amounted to 775.2 million tons. Based on production in 2023, Indonesia is the third-largest coal-producing country after China and India, accounting for 9% of total global production.

PT Bara Nusantara Energi (BNE) recorded a significant increase in coal production year-on-year, reflecting the company's growth. In recent years, production volume has continued to show a consistent upward trend, driven by the optimisation of the mining process. The increase reflects the company's commitment to meeting the growing domestic and international market demand. PT BNE's year-on-year increase in production can be seen in Figure 5 below.

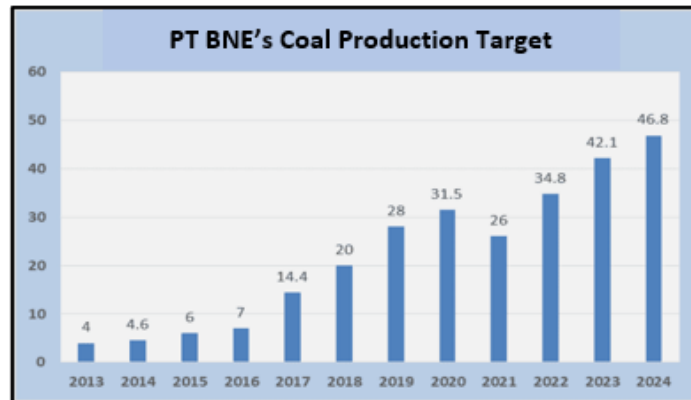


Figure 1. PT BNE's Coal Production Target

In 2023, PT BNE submitted a Work Plan and Budget (RKAB) for 2024 production, which was approved by the Ministry of Energy and Mineral Resources, with coal production target at 46.8 million tons and overburden (OB) target at 218 million BCM. PT BNE and its partner conducted mining activities at Pit Garuda. Pit Garuda contributes 11 million tons of coal, or 23.7% of the total coal production target for 2024. Based on the evaluation results for the first semester of 2024, the realization of coal production at Pit Garuda was only 4,656,662 tons, out of the target of 5,025,191 tons, achieving only 93% of the target. This indicates a negative deviation between planning and implementation at the field.

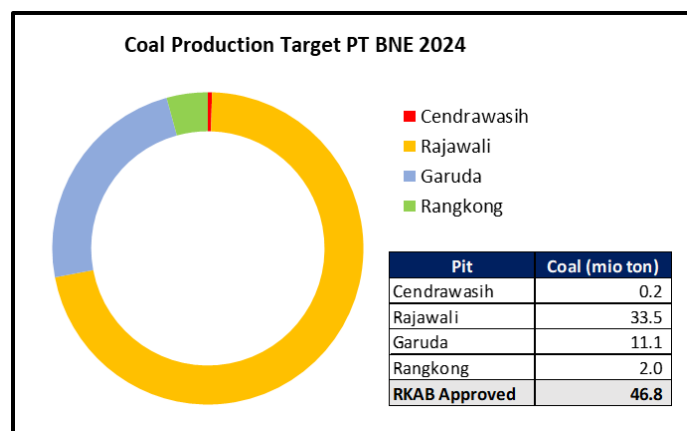


Figure 2. PT BNE's Coal Production Target 2024 (2024, Company Data)

One of the biggest challenges faced in mining operations at Pit Garuda during the first semester of 2024 was the accumulation of mud, which caused widespread flooding in the work area and severely disrupted operations. This situation was caused by several factors, including heavy rainfall, the limited capacity of the drainage system, and the lack of mud management facilities. In June 2024, the number of rainy hours was recorded at 155.90, which is 189% higher than the target of 82.33 hours. Moreover, total rainfall reached 775.40 mm, exceeding the monthly target of 267.12 mm by 290%. These conditions accelerated mud accumulation, as reflected in the substantial increase in mud volume. Specifically, mud inundation measured approximately 500,000 m³ in January 2024 and rose to nearly 980,000 m³ by the end of June 2024.

According to Tlhatlhetji and Kolapo (2021), heavy rains cause waterlogging in the mine area, which hinders the movement of heavy equipment and workers and forces the temporary suspension of mining operations, significantly reducing daily productivity. Lithologic types such as clay and mudstone have high binding capacity and low porosity, so when saturated with water, these materials form dense mud that is difficult to drain (Song, Zeyu et al., 2021). High rainfall causes water runoff that can carry fine materials from the mine surface, including clay and coal dust, accumulating in mud (Suwandhi, 2020). Bargawa et al. (2019) state that poorly designed drainage can cause excessive water and leading to mud accumulation. Fityus et al. (2008) also studied the shear strength characteristics of muds within the mine to ensure the stability of the lowwall. The result shows that mud properties can affect the stability of mine slopes adjacent to the excavation area. The study by Cao Ping et al. (2018) found that the condition of muddy areas in open pit mines significantly affects cycle time and operational inefficiency.

The accumulation of mud in the mining area directly disrupts operations by flooding the worksite, making it inaccessible. This prevents coal from being exposed and transported, leading to significant operational disruptions and reduced equipment productivity due to the increased need for mud removal. From a financial perspective, these constraints result in production deviations which could cause the loss of millions of US dollars in potential revenue, with further losses possible if not addressed quickly. From a regulatory standpoint, failing to meet the production targets set in the RKAB could lead to negative evaluations from the Ministry of Energy and Mineral Resources, potential cuts in future production allocations, damage to the credibility of expansion applications, and the risk of administrative sanctions. Regarding external stakeholders, delays in production could lead to contract penalties, reduced trust from buyers and investors, and greater reputational risks due to expectations of steady production. If not managed promptly, mud accumulation could threaten the overall sustainability of mine operations. Therefore, it is a critical issue that impacts technical, financial, regulatory, and stakeholder confidence, and thus requires a systematic and strategic approach to resolve.

RESEARCH METHOD

The right decision is determined by experience and must be built on a logical, systematic and analytically justifiable framework. According to Eisenhardt and Zbaracki (1992), an effective strategic decision-making process must be systematic, analytical and fact-based to produce solutions that are technically feasible and sustainable in the long term.

This research employs a mixed methods approach, combining qualitative and quantitative methods, designed to gain a comprehensive understanding of the mud accumulation problem at Pit Garuda. Qualitative methods were used to explore information related to the operational conditions of the mud-affected mine, the perceptions of internal stakeholders, and the technical practices applied. Meanwhile, quantitative methods support decision-making analysis, particularly during the evaluation stage of alternative solutions.

As the main framework, this research adopts the Kepner-Tregoe (KT) approach, which consists of four stages: Situation Appraisal (SA), Problem Analysis (PA), Decision Analysis (DA), and Potential Problem Analysis (PPA). In the Problem Analysis stage, the Fishbone Diagram is used to identify the root cause of the problem. Subsequently, in the Decision Analysis stage, the SMART (Simple Multi-Attribute Rating Technique) method is applied to assess various alternative strategies based on predetermined criteria.

Kepner-Tregoe is a handy tool in helping companies make more structured and informed decisions in material selection. With this model, companies can select materials that meet technical criteria and consider cost, sustainability and risk factors. This organised approach improves efficiency and ensures that decisions support the company's long-term goals (Hinely, 2019)

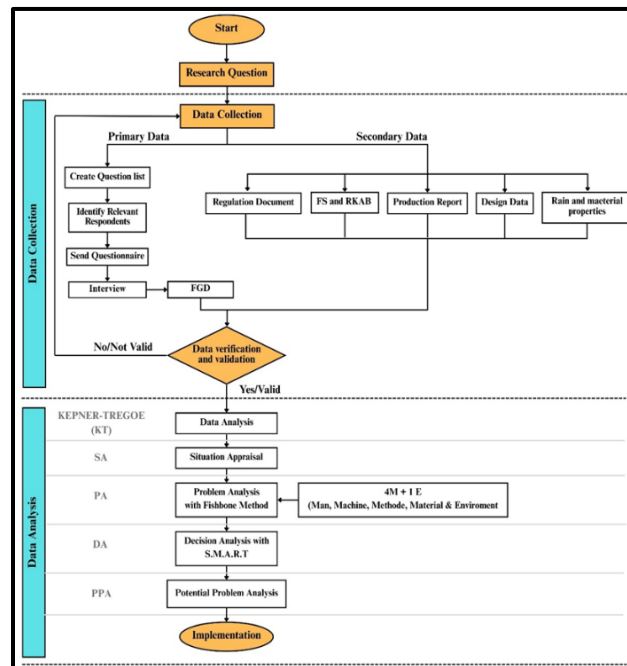


Figure 3. Research Design Diagram

Primary data refers to data collected directly from internal company sources with authority and direct involvement in the operational and decision-making processes in the Pit Garuda area. This primary data provides qualitative information. Three main methods were used: interviews, Focus Group Discussions (FGDs), and questionnaires. Interviews were conducted to gather information about the interviewees' views on the current operational situation, the mud problem in Pit Garuda, and the strategy options they believe can be implemented to overcome the problem. Focus group discussions were conducted in a limited discussion format involving the researcher and three Section Heads of Short Term Planning (STP), who play a role in making mining plans in the Pit Garuda. The aim of the discussion was to gain a broader understanding of the root causes of the mud problem and to explore alternative solutions to address it. The questionnaire was distributed digitally in order to obtain quantitative data, which will then be compiled and analysed further for use in the study.

Secondary data is obtained from existing and documented sources, such as reports prepared by the company. This secondary data provides quantitative and historical information that can be used to analyse patterns, trends, and comparisons between planning and implementation in the field. Secondary data was collected using various documents relevant to the mud problem at Pit Garuda.

RESULT AND DISCUSSION

This research uses the Kepner-Tregoe framework combined with the Fishbone method for root cause analysis and the SMART method to select effective alternative solutions. This integrated approach aims to provide rational, well-supported solutions that can be effectively implemented to address the problems caused by mud accumulation at Pit Garuda.

Situation Appraisal (SA)

The Situation Appraisal stage identified emerging concerns related to the impact of mud accumulation on mining operations during the first half of 2024. Each concern was analyzed regarding urgency, impact, and necessary follow-up.

Table 1. Situation Appraisal of Coal Production at Pit Garuda

No	Concern	Sub Concern	Action Statement	Timing	Trend	Impact	Process Needed	Priority
1	Readiness of Front Coal getting	The number of support units is not as planned, so preparing the front is hampered.	Accelerated arrival of support units at GARUDA Pit	H	H	H	DA	4

No	Concern	Sub Concern	Action Statement	Timing	Trend	Impact	Process Needed	Priority
2	Unit breakdown	Fleet composition change from coal to OB due to the fleet OB breakdown	Restore unit composition to the original plan so no coal-getting fleet is used for OB removal.	H	H	H	DA	2
		The CAT 6015 coal getting unit broke down several times and took a long time to get ready again.	Accelerate the maintenance of breakdown units and provide spare units	H	H	H	DA	3
3	High rainfall intensity	Slippery time exceeds the pre-planned budget	Develop a more optimized slippery strategy	M	M	H	PPA	7
		Rainy hours exceeded the plan, reducing working hours	Improve the accuracy of rainfall hour projections in collaboration with BMKG	L	M	M	PPA	8
4	Coal Delay	Coal is held up by road access so that it cannot be mined	Change the mining sequence to avoid the use of near exposures as a path	L	M	L	PPA	9
		Coal is submerged in historical mud accumulation.	Find out the cause of mud accumulation in the coal front area	H	H	H	PA	1
5	Manpower Readiness	The number of hauler and loader operators has not met the needs, so	Fulfillment of hauler and loader operators	M	M	H	DA	5

No	Concern	Sub Concern	Action Statement	Timing	Trend	Impact	Process Needed	Priority
		some units stand by						
		The number of supervisors and engineering teams does not match the number of work areas, so the progress is hampered.	Fulfillment of the supervisors and the engineering team	M	M	H	DA	6

Problem Analysis (PA)

Based on the Situation Appraisal, the primary issue identified is the accumulation of mud, which obstructs coal mining operations at Pit Garuda. This problem has developed gradually over several years and has not been addressed comprehensively, significantly affecting the ability to meet coal production targets.

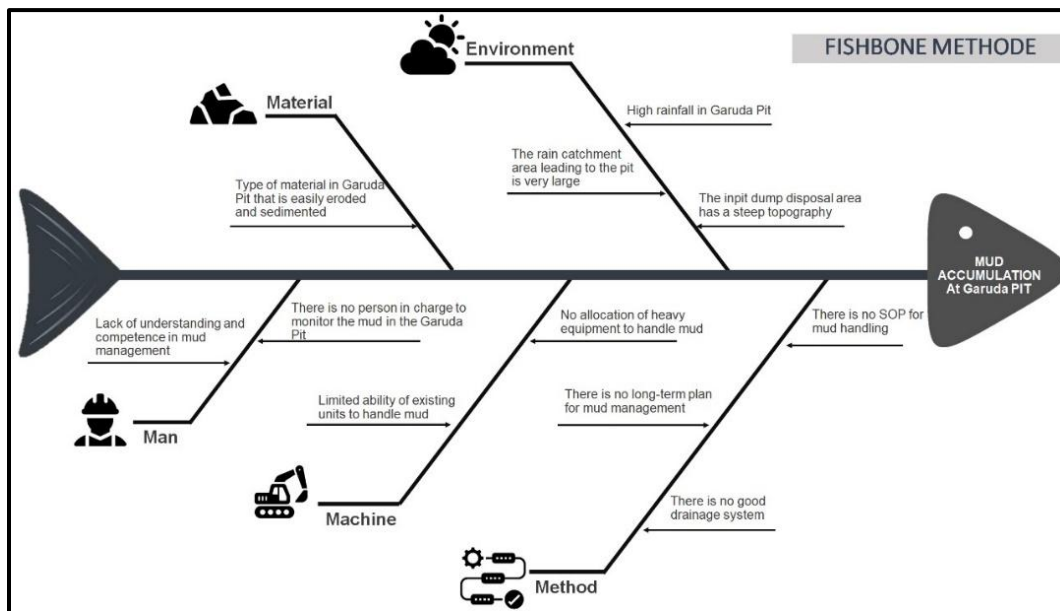


Figure 4. Fish Bone of Mud Accumulation

1. Machine Factor

- a. No additional allocation of heavy equipment to handle mud

There is no plan to use equipment such as slurry pumps or specialized excavators to rehandle mud in the annual equipment settings.

b. Limited ability of existing units to handle mud

The existing tool is very limited in availability due to the many other areas that require pumping and the productivity is very low.

2. Method

a. There is no long-term plan for mud management.

Mud handling is still incidental or done when it is urgent, like now. As a result, mud continues to accumulate because it was not handled in the previous period.

b. There is no SOP for mud handling.

Standard Operating Procedure documents related to mud handling have not been prepared, causing slow mud control.

c. There is no good drainage system.

In the inpit dump disposal area, a good drainage system has not been established. Rainwater runoff will flow freely to the lowest area, so that mud sedimentation will form quickly in the sump area.

3. Man

a. Lack of understanding and competence related to mud management

The understanding of personnel in the field or engineering team regarding mud management is still relatively low.

b. No person is in charge of monitoring the mud at Pit Garuda.

Personnel directly appointed to monitor the mud problem have also not been determined by the company.

4. Material

a. Type of material at Pit Garuda that is easily eroded and sedimented

The inpit dump disposal area at Pit Garuda is dominated by very fine-grained clay material. Clay material also tends to absorb water easily.

5. Environment

a. High rainfall and rainy hours

Compared to the 2024 rainfall hour plan, the actual rainfall is over 132%. The actual rainfall hours at Pit Garuda in January-June exceeded the plan by 113%.

b. The inpit dump disposal area has a steep topography

The sump at Pit Garuda must accommodate rainfall runoff from the steep inpit dump disposal area.

c. The rain catchment area leading to the pit huge

The sump at Pit Garuda collects rainwater from a total catchment area of 532 Ha. The larger the catchment area, the greater the runoff water discharge will enter the Pit area.

Decision Analysis (DA)

After the Situation Appraisal and Problem Analysis identified that mud accumulation at Pit Garuda work area was the main factor causing coal production underachievement, the next step was to formulate the right solution through the Decision Analysis process.

The SMART method determines alternative solutions to handling mud at Pit Garuda, especially those related to heavy equipment or mud rehandling methods. This method is a decision-making method that assesses alternative solutions objectively, measurably, and relevantly. SMART has 8 stages for the analysis, that is explained below.

1. Identify the Decision Maker

In the context of this research, the primary decision maker is the Head of Mine Plan Department or the technical team directly responsible for mine planning and controlling production progress at Pit Garuda.

2. Identify the Alternatives Courses of Action

In the next stage, alternative solutions were determined to handle the mud problem at Pit Garuda. There is three option obtained:

a. Conventional loading with the CAT 6015 excavator (Option 1)

This alternative method uses an excavator to load mud material, which is then transported by a dump truck to the disposal area. Technically, this approach is similar to the overburden (OB) removal and transportation process. However, it requires specific techniques, such as blending the mud and constructing barriers, to restrict the area from which mud can be loaded. The following points summarize key aspects related to this conventional loading method.

b. Pumping with a slurry pump into the existing void (Option 2)

The next alternative involves using a slurry pump to remove the mud. A slurry pump is a specialized pump designed to handle liquids that are thicker than water, such as liquid mud. This method will utilize a slurry pump connected to a high-density polyethylene distribution pipe (HDPE), along with booster pumps if necessary.

c. Slurry pump with Geotube as a reservoir (Option 3)

The third alternative involves using geotextile tubes, known as geotubes, as reservoirs for storing pumped mud. Geotubes serve as temporary storage units that help manage limited disposal space by holding and allowing the mud to dewater gradually. This method is an alternative to overcome the limited void capacity.

Identify The Attributes With Are Relevant

The next step is to determine the criteria for evaluating the alternatives described above. These criteria are chosen based on the challenges encountered during the implementation of each option. It is essential that the criteria are closely related to the alternatives to ensure a proper and effective decision-making process. The selection of criteria is based on information

gathered from interviews, supported by technical data as explained in the alternative identification section.

The criteria are divided into two main categories: cost and benefit. The benefit category is further divided into two subcategories: progress effectiveness and impact. This classification helps to assess the advantages and disadvantages of each alternative from different perspectives. In total, six criteria are used to evaluate the three alternatives: preparation, additional treatment, productivity, availability of storage, safety, and environment.

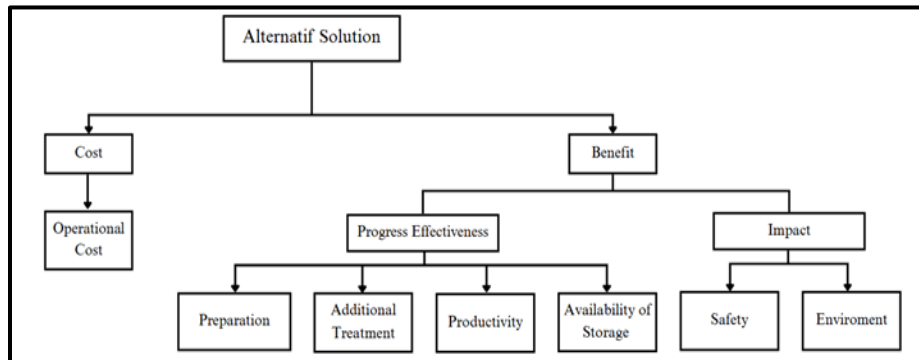


Figure 5. Value Tree of Decision Making

Assign Value to Measure Performance of Each Alternative on Each Attribute

After establishing the criteria, the next step is to assign a scoring scale to each attribute. This scoring scale is determined through Focus Group Discussions (FGDs). The scale serves as a reference for evaluating the performance of each alternative in the following stages. Assigning scores to the attributes helps to convert qualitative factors into quantitative values, making the assessment of each alternative more transparent and measurable. The following is a score scale table for each criterion.

Tabel 4. Criteria Value Weighting Provisions

No.	Criteria	Requirement	Class	Score
1	Preparation	A faster and simpler preparation process has a bigger score	Slow	25
			Medium Slow	50
			Medium Fast	75
			Fast	100
2	Additional Treatment	More blending and additional treatment needs have a smaller score	More Need	25
			Fairly Need	50
			Less Need	75
			Not Needed	100
3	Productivity	Higher productivity of rehandle mud has a bigger score	Low Productivity	25
			Medium-Low	50
			Medium-High	75
			High Productivity	100
4	Availability of Storage	More mud storage availability has a bigger score	Less Available	25
			Fairly Available	50
			Mostly Available	75
			Available	100

No.	Criteria	Requirement	Class	Score
5	Safety	Lower safety risk has a bigger score	High Risk	25
			Medium-High	50
			Medium-Low	75
			Low Risk	100
6	Environment	More impact on environmental pollution has a bigger score	More Impact	0
			Less Impact	50
			Fair Impact	75
			No Impact	100

To evaluate the sub-criteria mentioned above, a questionnaire was conducted. The respondents were from the Short Term Planning (STP) Department and Garuda Operation Department. Based on the questionnaire results, scores were assigned to each criterion.

For the first sub-criterion, which relates to preparation time, respondents rated the alternatives according to how quickly they could be prepared. Option 1 was considered the fastest and received a score of 85. Option 2 scored 60, while Option 3 was the slowest and received a score of 25.

Table 5. Preparation Sub-Criterion Scoring

No	Option	Respondent					Average
		R1	R2	R3	R4	R5	
1	Option 1	75	100	75	100	75	85
2	Option 2	50	75	50	75	50	60
3	Option 3	25	25	25	25	25	25

The next sub-criterion concerns the need for additional treatment. According to the questionnaire results, Option 2 requires minimal blending or additional treatment. Option 1 requires a moderate amount of blending, while Option 3 demands extensive blending and additional treatment. Therefore, Option 2 is considered the best in terms of the additional treatment sub-criterion.

Table 6. Additional Treatment Sub-Criterion Scoring

No	Option	Respondent					Average
		R1	R2	R3	R4	R5	
1	Option 1	50	25	50	50	25	40
2	Option 2	75	75	50	50	50	60
3	Option 3	25	50	25	50	25	35

The next sub-criterion is the productivity of rehandling the mud. The questionnaire results indicate that respondents rated Option 2 as having the highest productivity, Option 3 was considered to have medium to high productivity, while Option 1 was rated the lowest.

Table 7. Productivity-Criterion Scoring

No	Option	Respondent					Average
		R1	R2	R3	R4	R5	
1	Option 1	25	25	25	25	25	25
2	Option 2	100	100	75	100	100	95
3	Option 3	75	75	75	75	75	75

Regarding the sub-criterion of availability of storage, the results show that Option 2 received the highest score, indicating reasonably good availability. Option 3 received a moderate, while Option 1 had the lowest score.

Table 8. Availability of Storage Sub-Criterion Scoring

No	Option	Respondent					Average
		R1	R2	R3	R4	R5	
1	Option 1	50	25	50	25	25	35
2	Option 2	50	50	25	50	50	45
3	Option 3	25	50	50	50	25	40

In the safety sub-criterion, respondents assessed Option 1 as posing a high risk to occupational safety. In contrast, Options 2 and 3 were considered to have moderately high risks. Option 1 received a score of 35, while Option 2 scored 50, and Option 3 scored 55.

Table 9. Safety Sub-Criterion Scoring

No	Option	Respondent					Average
		R1	R2	R3	R4	R5	
1	Option 1	25	50	25	50	25	35
2	Option 2	50	50	50	50	50	50
3	Option 3	50	50	50	50	75	55

The final sub-criterion relates to environmental impact. Respondents evaluated Option 1 as having a low environmental impact, Option 2 as having a significant impact, and Option 3 as having no impact on the environment. Based on this assessment, Option 1 received a score of 50, Option 2 scored 25, and Option 3 achieved the highest score of 100.

Table 10. Environment Sub-Criterion Scoring

No	Option	Respondent					Average
		R1	R2	R3	R4	R5	
1	Option 1	50	25	50	50	25	40
2	Option 2	75	75	50	50	50	60
3	Option 3	25	50	25	50	25	35

The scoring of each sub-criterion can be summarized as in Table IV.13 below.

Table 11. Summary Direct Scoring Sub-Criteria

Attributes	Preparation	Operational	Productivity	Availability of Storage	Safety	Environment
Option 1	85	40	25	35	35	60
Option 2	60	60	95	45	50	50
Option 3	25	35	75	40	55	90

In addition to calculating the following scores, there is a summary of the costs required for each alternative.

Table 12. Cost Required for each Option

Options	Cost (Rp)	Rate (Rp/m3)
Option 1	105,841,348,823	53,932
Option 2	112,323,621,716	49,058
Option 3	97,041,803,011	42,384

Determine a Weight for Each Attribute

Based on the sub-criteria and their assigned scores, the weight for each attribute is then established. Each attribute contributes differently and varies in importance. The weighting for each attribute is determined using the results from the questionnaire.

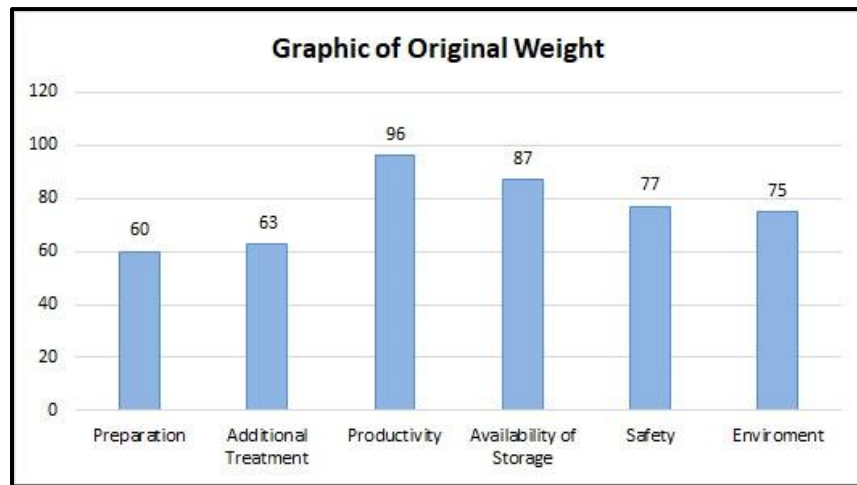


Figure 7. Graphic of Original Weight Each Attribute

Next, the above weights are normalized using the following formula.

$$\text{Normalized Weight} = \frac{\text{Original Weight}}{\text{Total Original Weight}} \times 100\%$$

The weights assigned to each attribute are then normalized. The following presents the results of this weight normalization for each attribute.

Table 13. Calculated Normalized Weight

No.	Attributes	Original Weights	Normalized Weight
1	Preparation	60	0.13
2	Operational	63	0.14
3	Productivity	96	0.21
4	Availability of Storage	87	0.19
5	Safety	77	0.17
6	Environment	75	0.16

For Each Alternative, Take a Weighted Average of Values Assigned to That Alternatives

After determining the normalized weights, the next step is to adjust the attribute scores from step 4. This is done by multiplying each attribute score for every alternative by the normalized weight. By doing so, the total benefit score for each alternative can be calculated.

Table 14. Total Weight Value for Option 1

No.	Attributes	Normalized Weights	Value	Normalized Weights x Value
1	Preparation	0.13	85	11.14
2	Operational	0.14	40	5.50
3	Productivity	0.21	25	5.24
4	Availability of Storage	0.19	35	6.65
5	Safety	0.17	35	5.88
6	Environment	0.16	60	9.83
Total				44.24

Table 15. Total Weight Value for Option 2

No.	Attributes	Normalized Weights	Value	Normalized Weights x Value
1	Preparation	0.13	60	7.86
2	Operational	0.14	60	8.25
3	Productivity	0.21	95	19.91
4	Availability of Storage	0.19	45	8.55
5	Safety	0.17	50	8.41
6	Environment	0.16	50	8.19
Total				61.17

Table 16. Total Weight Value for Option 3

No.	Attributes	Normalized Weights	Value	Normalized Weights x Value
1	Preparation	0.13	25	3.28
2	Operational	0.14	35	4.81
3	Productivity	0.21	75	15.72

No.	Attributes	Normalized Weights	Value	Normalized Weights x Value
4	Availability of Storage	0.19	40	7.60
5	Safety	0.17	55	9.25
6	Environment	0.16	90	14.74
Total				55.39

The results of multiplying the scores by the normalized weights are then compiled into a single table to facilitate comparison among the available alternatives. The summary table is presented below.

Table 17. Aggregate Value for Each Alternative Solutions

No	Attributes	Preparation	Operational	Productivity	Availability of Storage	Safety	Aggregated of Weighted Value
1	Option 1	85	40	25	35	35	60
2	Option 2	60	60	95	45	50	50
3	Option 3	25	35	75	40	55	90

Make A Provisional Decision

The next step is to identify the provisional preferred alternative. This decision is based on considering both the total cost involved and the combined benefit scores calculated in step 6.

Table 18. Total Cost and Aggregate Benefit of each Alternatif

Alternatives	Total Cost (Billion Rupiah)	Aggregated Benefits
Option 1	105.84	44.24
Option 2	112.32	61.17
Option 3	97.04	55.39

To support the analysis, the data above is presented in a graph, with the cost represented on the negative X-axis and the total benefit on the Y-axis. An alternative is considered better if it has a lower cost and a higher total benefit. As shown in Figure IV.7, Options 2 and 3 represent the most efficient choices among the alternatives.

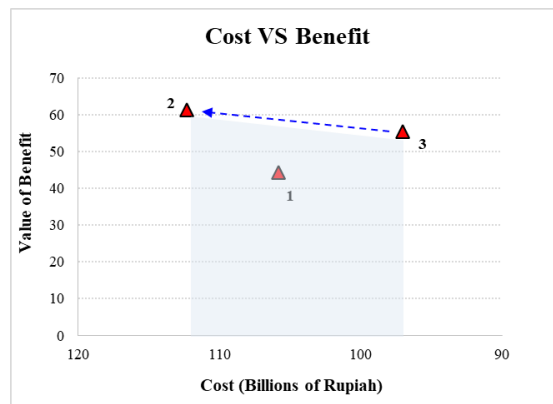


Figure 8. Graphic Cost vs Benefits

From the graph above, it can also be seen that Options 2 and 3 have a relatively small difference in benefits. If calculated, the aggregate benefit difference from Option 3 to 2 is 5.78 points with an increase in cost of 15.28 billion Rupiah. This also means that 2.65 billion Rupiah is required for each additional point from Option 3 to 2. Given the small difference in benefits and the associated cost, the provisional preferred choice is Option 2, which involves using a slurry pump to void.

Table 20. Comparison of Alternative Option 2 and Option 3

Alternative	Option 2		Billion Rupiah/Point
	Option 2	Option 3	
	112.32	61.17	
Option 3	97.04	15.28	5.78
	55.39	2.65	

Perform Sensitivity Analysis

The final step in the decision analysis using the SMART method is to perform a sensitivity analysis of the alternatives. This analysis evaluates how robust each alternative is when there are changes in the priorities or weights assigned to the criteria. In this study, the weights of the Progress Effectiveness and Impact criteria will be adjusted to test the alternatives. First, the weights of the three attributes under the Progress Effectiveness criterion—preparation, operational productivity, and availability of storage—will be set to zero, and the total scores of the alternatives will be recalculated. Then, the same process will be applied to the Impact criterion by setting the weights of its two attributes—safety and environment—to zero. This approach helps to understand how changes in attribute importance affect the overall evaluation of each alternative.

Table 21. Aggregate of Weighted Value after Sensitivity Analysis

Alternatives	Aggregate of Weighted Value (Progress = 0)	Aggregate of Weighted Value (Original)	Aggregate of Weighted Value (Data Generated = 0)
Option 1	47.34	44.24	42.70
Option 2	50.00	61.17	66.72
Option 3	72.27	55.39	47.01

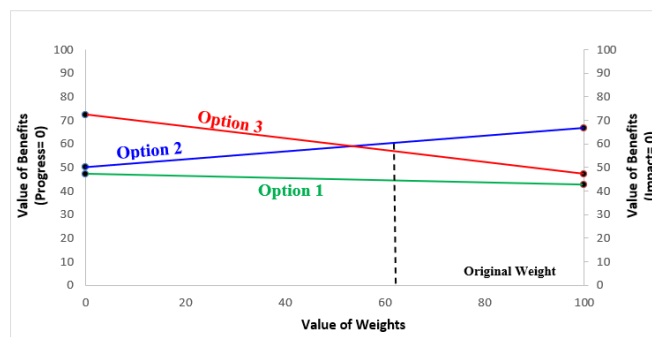


Figure 9. Sensitivity Analysis Result

The sensitivity analysis results show that Option 3's total benefit increased when the Progress Effectiveness criterion was removed, while Option 2's benefit increased when the Impact criterion was removed. This indicates that Option 3 performs better in terms of impact, while Option 2 excels in Progress Effectiveness. Similarly, Option 1 also showed an increase in benefit when the Progress Effectiveness criterion was removed, like Option 3. Overall, this analysis confirms that Option 2 remains a strong choice for the problem, mainly due to its advantage in the Progress Effectiveness criterion.

Potential Problem Analysis

After selecting an alternative using the SMART decision analysis, the next step is to analyze potential problems that might arise during implementation. These issues could hinder the success of the chosen alternative or even lead to operational failure. Therefore, a thorough analysis of possible future problems is necessary. Conducting a Potential Problem Analysis (PPA) helps the company prepare for challenges that may occur, ensuring smooth operation and achieves its objectives effectively.

Table 22. Potential Problem Analysis Result

No.	Potential Problem	Consequence	Possible Cause	Preventive Action	Contingent Action
1	The mud holding capacity (void) is full before the slurry pump project is completed, or has not reached the target	Pumping stops and mud can spill over into other areas, drawing operational or environmental pollution	Inaccurate calculation of storage capacity and too fast slurry pumping	Recalculated the mud storage (void) and provided an additional storage location before the slurry.	Raising the height of the existing void embankment as needed, and regular control of mud rise
2	The mud volume was depleted before the project was carried out, and the remaining project volume has not yet been depleted.	The company is subject to equipment standby penalties	Inaccurate mud calculation at the beginning of project planning	Conduct an echosounder actual mud elevation at the sump and compare it with the manual sounding data with a stick.	Optimize the pumpable area and provide a sump area switchover for the slurry pump.
3	Delayed arrival of the slurry pump unit at the site	The mud problem was not dealt with quickly, and the coal could not be mined in time	Slurry pump unit mobilization issues or limited units available from vendors	Select a trusted vendor and agree on the TOR that the slurry unit must be delivered on time.	Diverting units from other project locations with lower priorities
4	Mud remains at the end of the project even though the	Submerged coal cannot be mined yet.	Non-optimal SG during pumping or significant mud addition	Improve drainage around the pumping area and create a structure	Extend the contract with the pumping vendor or exercise other options, such

No.	Potential Problem	Consequence	Possible Cause	Preventive Action	Contingent Action
	target volume has been reached.		due to physical conditions such as high rainfall	to prevent rain runoff from entering the pumping site.	as conventional loading.

Proposed Business Solutions

To reduce coal delay due to mud problems at Pit Garuda, several alternatives will be selected to rehandle the accumulated mud volume. Three alternatives can be selected to handle the problem, among others:

1. Conventional Loading with Excavator 2 x CAT 6015 (Option 1)
2. Slurry Pump to void with 4 x Eddy Pump HDX 8000 (Option 2)
3. Slurry Pump to geotube with 2 x Eddy Pump HDX 8000 (Option 3)

The results show that Option 2 and Option 3 are the most efficient choices. Option 2 has the highest aggregate benefit (61.17 points) but it also costs the most (112.32 billion Rupiah). Further, Option 3 requires the lowest cost (97.04 billion Rupiah) to deal with the mud problem, but the aggregate benefit is slightly lower than that of Option 2 (55.39 points). Option 1 has the lowest aggregate benefit (44.24 points). Meanwhile, Option 3 performs best in terms of impact, while Option 2 is the best for progress effectiveness.

Considering the plan to pursue coal production at Pit Garuda as soon as possible, Option 2 is the best choice. Although Option 3 has the lowest cost, it doesn't perform as well in terms of progress. Option 2 deals with the mud problem more efficiently at a lower cost than the other alternatives. Thus, mud at Pit Garuda can be handled efficiently and at minimal cost, and coal submerged in mud can be mined immediately.

Based on the sensitivity analysis, Option 2 is sensitive to changes in the impact criteria, indicating that it has an advantage in this area. Meanwhile, Option 3 is more sensitive to changes in the progress criteria, suggesting it performs better in terms of progress. Taking these sensitivity results into account, as well as the company's need to handle the mud issue efficiently, Option 2 was ultimately chosen. This involves using a slurry pump to resolve the mud accumulation problem.

CONCLUSION

This study concludes that the accumulation of mud at Pit Garuda severely impacted coal production activities at PT BNE, leading to a shortfall in achieving the 2024 production target. Using the structured Kepner-Tregoe framework, which includes Situation Appraisal, Problem Analysis with the Fishbone Diagram, Decision Analysis using the SMART method, and Potential Problem Analysis, this research identifies the root causes of the issue and systematically evaluates three alternative solutions.

The decision analysis shows that the slurry pump method is the most effective and practical solution for quickly removing the mud. It is more efficient than the conventional loading and geotube dewatering methods in terms of technical readiness, operational effectiveness, safety, environmental impact, and speed of implementation. The chosen solution aims to remove about 2,289,592 m³ of slurry within 3.5 months, ensuring minimum specific gravity (SG) of 1.3 and a flow rate of at least 1,400 m³/hour.

By implementing the slurry pump strategy, along with proactive risk management and continuous monitoring, the company expects to restore its production capacity, prevent further delays, and maintain its regulatory compliance and reputation. This study highlights the importance of a systematic, data-driven decision-making process for addressing complex operational challenges in mining, especially under uncertain conditions like weather-related disruptions. Future research could explore the adaptability of this approach at other mining sites and in different operational settings.

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