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COMPARATIVE ANALYSIS OF BATUPACK (SILICIFIED COAL) HANDLING STRATEGIES AT PT. BINA SARANA SUKSES, PT. MME SITE

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Abstract
The coal mining process at PT. Bina Sarana Sukses (PT. BSS) site PT.MME often encounters challenges in controlling coal quality. One of the main issue in the open-pit mine is the presence of batupack or silicified coal as impurities within nearly all coal seams, appearing both laterally as keybeds and as lens-shaped fragments. These impurities affect coal quality and hinder mining operations, while their hardness contributes to wear and damage o coal processing equipment, reducing operational efficiency. To address this, PT. BSS uses two strategies to separate batupack from coal: manual selective (handpicking) and bucket crusher excavators (BCE). A comparative analysis of these methods is required to evaluate technical feasibility and cost-effectiveness, to identify the most efficient approach to produce zero-contaminant coal and to set production targets. The study is conducted through a descriptive qualitative approach, which integrates preparation, scholarly review, compilation of primary and secondary information, and the stages of processing and analytical evaluation. The findings are expected to offer recommendations on the most effective and economical strategy for managing batupack impurities in coal mining operations.

Keywords: Coal, Batupack, Silicified Coal, Manual Selective, Bucket Crusher Excavator

INTRODUCTION

PT. Bina Sarana Sukses (PT. BSS) is one of the leading national private subsidiaries of PT. Aswana Dhanakirti Sinergi (ADS Group) operating in the mining services sector. PT. BSS currently operates at several project sites spread across most of Kalimantan and Sumatra, one of which is the PT. MME mining project site located in Lawang Kidul Subdistrict, Muara Enim Regency, South Sumatra Province, with a Production Operation Mining Business License (IUP OP) area of 1,587 hectares. The PT. MME site has been conducting coal mining operations since early 2022 using an open-pit mining system that employs a combination of shovels and dump trucks. The mining process carried out by PT. BSS at the PT. MME site includes land clearing, topsoil stripping, overburden removal, coal cleaning, coal extraction and transportation, and coal crushing. Coal mining that implements Good Mining Practice (GMP)—or the application of sound mining engineering principles as outlined in the Ministry of Energy and Mineral Resources Regulation No. 1827K/30/MEM/2018 (—is the solution to ensuring that mining activities are conducted responsibly and sustainably. PT. MME has diverse requirements regarding the criteria and quality of coal to be marketed to buyers. These conditions serve as guidelines for PT. BSS in controlling the quality and quantity of coal in accordance with PT. MME's requests, by ensuring the quality parameters of the coal to be marketed.

In coal mining operations at the PT. MME site, PT. BSS frequently encounters challenges related to quality control. One issue faced at the open-pit mine at the PT. MME site is the presence of batupack or silicified coal as a contaminant, found in nearly all coal layers, whether in lateral strata (keybeds) or lens-shaped fragments (lenses/spotty). Batupack is commonly known by many names, such as silicified coal or silicified wood. Batupack material forms from fossilized plant residues due to structural changes resulting from the replacement of components with silica. Silica minerals form within cracks, intercellular spaces of plant cells, and in the fluid remaining within plant cells. The physical appearance of batupack within coal layers is layered and lens-shaped and is nearly identical to black coal, but it possesses a higher hardness value (Hidayatullah & Jati, 2018). The appearance of batupack is almost identical to that of coal (Figure 1). Macroscopically, batupack appears gray to dull black in coal layers. The size of its constituent minerals ranges from 0.5–5.0 mm with a sub-granular grain shape, and it has a hardness level of approximately 15,000 kPa to 50,000 kPa. In terms of composition, this material is dominated by quartz with a small organic content (Utami et al., 2017) . The batupack sample from the PT. MME site that underwent uniaxial compressive strength (UCS) testing had a compressive strength of 39.63 MPa.

Figure 1. Batupack (Silicified Coal)

The presence of batupack in the form of lenses (lenses/spotty) within a coal seam is a primary factor complicating the control of mining processes at the mining face. This difficulty is further exacerbated by complaints regarding damage or wear to coal processing equipment due to the hardness of the batupack, which impacts the optimization of coal handling and transportation (Zuhri et al., 2025) . The presence of batupack has caused the coal processing unit to experience a 20% decline in physical availability (PA), with the actual average PA at 70% of the target PA of 90%. This, of course, results in a reduction in the production capacity of crushed coal from the target of 3,000 tons/day to 2,300 tons/day.

The separation of batupack from coal is generally carried out using a manual selective method (handpicking) assisted by a 20-ton-class excavator. This method has been in use since the initial contract for the PT. BSS site at PT. MME in 2022 for the operation of batupack separation from coal. Currently under development is a method for separating batupack using bucket crusher technology mounted as an excavator attachment. The installation of bucket crushers on excavators is based on size specifications in the 20-ton, 30-ton, and 40-ton classes. Based on the issues described above, a comparative analysis is needed of strategies for handling batupack using the manual selective method (handpicking) and the bucket crusher excavator, based on technical studies and cost analysis, so that an effective and efficient (minimum-cost) method for separating batupack from coal can be determined in an effort to meet the quality target (zero-contaminant coal) and the quantity of coal to be marketed.

METHOD

This research is of a descriptive qualitative nature. According to (Sugiyono, 2015) , the descriptive method is a research approach used to describe or analyze study results, but is not intended to draw general conclusions. The research stages include data collection, analysis, inteIDRretation, and ultimately the formulation of conclusions based on the results of that analysis.

The collected data consists of primary and secondary data. Primary data is information obtained directly through observation and field recording, consisting of:

1. Collection of cycle time and sampling data from 30 randomly selected samples of 20-, 30-, and 40-ton class excavator bucket crusher units.
2. Collection of cycle time and sampling (spot checks) of 30 randomly selected samples from the selective screening of 20-ton class excavator units to support manual selective operations.
3. Field observations, consisting of surface lithological observations and surface stratigraphic measurements at 10 sample points with an observation interval of 50 m, as well as the collection of 10 samples of batupack and coal fragments/grains.

Meanwhile, secondary data serves as research support, obtained through literature and company reports. This data collection was conducted through literature reviews and company studies. The literature review includes national and international journal publications, previous research results, literature, and various other relevant sources to support the research. The company study of PT. Bina Sarana Sukses involved collecting standard operating procedure (SOP) data from the Operations, Plant, and Engineering Departments, as well as analyzing the costs incurred in coal handling activities. The types of secondary data collected in this study include:

1. The 2025 Joint Sign-Off (JSO) between PT. BSS and client site PT. MME, which includes standard operational parameters and production targets.
2. Location maps and batupack distribution data from the Quality Control Department of PT. MME.
3. Data on specifications and availability of equipment for batupack handling activities.
4. Data on the costs incurred for batupack management activities.

After data collection, the primary and secondary data were processed as follows:

1. Conducting an analysis to identify the distribution patterns of batupack collected from the field, including surface lithological observations, surface stratigraphic measurements, and sampling of batupack and coal clumps/grains.
2. Processing cycle time data and conducting spot checks on selective units and bucket crusher excavators to analyze productivity using effective working hour data.
3. Conducting a cost analysis of batupack handling activities using manual, selective, and bucket crusher excavator methods.
4. Conducting a comparative analysis of batupack separation handling methods—manual, selective, and bucket crusher excavator—to assess their effectiveness in meeting the zero-contaminant coal production target. The method used to determine the batupack handling strategy is the Simple Additive Weighting (SAW) method. This model is also known as the Weighted Sum Model (WSM) or Scoring Method (SM), and is one of the most widely used techniques in Multiple Attribute Decision Making (MADM). The basic principle is that the normalized criterion values for each alternative are multiplied by the criterion weights, and the alternative with the highest score is selected as the best option. According to (Kusumadewi et al., 2006), SAW is a weighted summation method in which the performance ratings of each alternative are summed based on attribute weights. This process requires the normalization of the decision matrix (X) so that all alternative ratings can be compared.

$$R_{ij} = \begin{cases} \dfrac{x_{ij}}{\underset{i}{Max}\, x_{ij}} \\ \\ \dfrac{\underset{i}{Min}\, x_{ij}}{x_{ij}} \end{cases} \quad \text{......(1)}$$

where:
R_{ij} = the normalized performance rating; Max x_{ij} = the maximum value for each criterion; Min x_{ij} = the minimum value of each criterion; x_{ij} = the attribute value associated with each criterion

The preference values for each alternative (V_i) are given as follows:

$$V_i = \sum_{j=1}^{n} w_j r_{ij} \quad \text{......(2)}$$

The preference value for each alternative (V_i) is determined by multiplying the normalized performance rating of alternative A_i on attribute C_j by the criterion weight, where i= 1,2,...,m and j = 1,2,...,n. The alternative with the largest V_i value is considered the best choice.

The steps for applying the SAW method include:

1. Determining the criteria (C_i) used as the basis for decision-making.
2. Determining the suitability rating of each alternative against the criteria.
3. Construct a decision matrix based on the criteria (C_i), then normalize it according to the type of attribute (benefit or cost) to obtain the normalized matrix R.
4. Rank the alternatives by summing the results of multiplying matrix R by the preference weights, so that the alternative with the highest score (e.g., A1) is selected as the best option.

The criteria for selecting a batupack handling method are divided into technical and economic aspects.

RESULTS AND DISCUSSION

Coal Seam Distribution Pattern

In the study area, there are six coal seams in Pit 1 East, namely seam A, seam B, seam C, seam D, seam E, and seam F, as well as one coal seam in Pit 2 East, namely seam G. The coal seams that are the focus of the batupack (silicified coal) distribution mapping are Seam D, Seam E, and Seam F. This is because in Seams A, B, C, and G, no batupack was found, either in the form of lenses (spotty) or layers (keybed).

Coal seam D has a thickness of approximately 15 meters with a dip of approximately 14°. Seam D is divided into five sections: seam D1, seam D2, seam D3, seam D4, and seam D5. The interburden between seam D1 and D2 consists of a claystone parting with a thickness of 5–7 cm. The interburden between Seams D2 and D3 consists of a claystone parting with a thickness of 12–15 cm. The interburden between Seams D3 and D4 is a relatively thick claystone layer with a thickness of 1.5–2 m. The interburden between Seams D4 and D5 consists of a claystone layer with a thickness of 7–10 cm. The distribution of the batupack (silicified coal) layers in seam D5 is found in the roof and floor in a layered (keybed) pattern and is scattered in lenses (spotty) within the body of coal seam D5, with a batupack thickness of 20–30 cm. The cross-sectional details of seam D are shown in Figure 2.

Coal seam E, which is 5–6 meters thick with a dip of 10–12°, is divided into four seams: seam E1, seam E2, seam E3, and seam E4. The E1-E2 seam interburden contains a thin claystone parting 0.2 m thick. The E2-E3 seam interburden contains a thin claystone parting 0.04–0.05 m thick. Furthermore, the E3-E4 interburden seam also contains a thin claystone parting with a thickness of 0.04–0.1 m. The distribution of the batupack (silicified coal) layers in Seam E is found within the coal bodies of Seam E2 and Seam E3, occurring in a lens-like (spotty) pattern. A detailed cross-section of Seam E is shown in Figure 3.

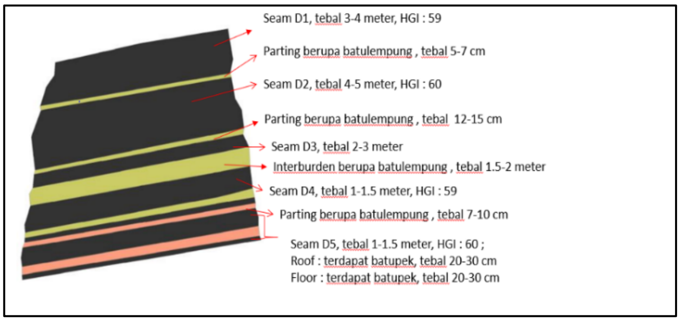

Figure 2. Cross-Section of Seam D

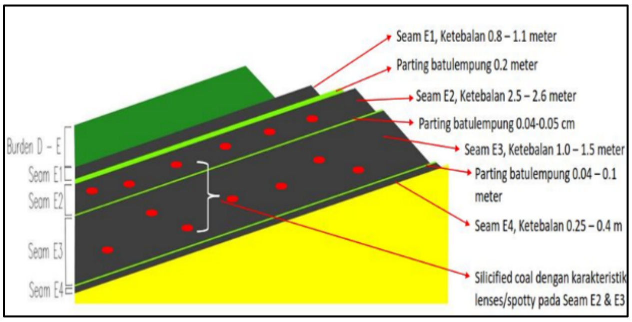

Figure 3. Cross-Section of Seam E

Coal seam F has a thickness of 7–8 meters with a dip of 10–12°. The distribution of batupack (silicified coal) layers in seam E is found on the floor of seam F, occurring in a layered (keybed) pattern with a thickness of 0.15–0.22 m. For details of the cross-section of seam F, see Figure 4 below:

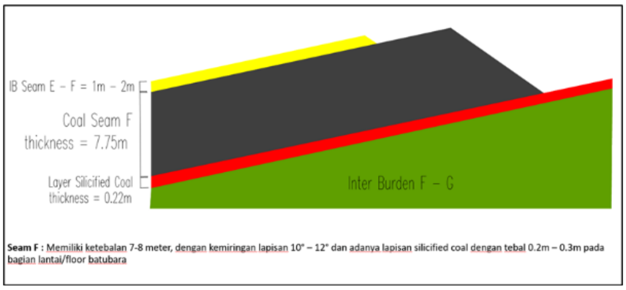

Figure 4. Cross-Section of Seam F

Productivity of the Manual Selective Method and Bucket Crusher Excavator

Generally, the coal processing carried out by mining companies in Indonesia includes mixing, crushing/grinding, and coal washing (Permana, 2011). Holders of Production Operation IUP and Production Operation IUPK are required to process coal to increase its value-added, either independently or through cooperation with other companies holding IUP or IUPK. This value-added enhancement is achieved through coal processing activities (Government Regulation No. 5 of 2021) . The coal processing activities carried out at the PT. BSS site of PT. MME include the separation of impurities from coal, as well as the crushing and grinding of coal. The manual selective (MS) process at the PT. BSS site of PT. MME, which involves separating batupack from coal through handpicking by daily casual workers (THL) with support from an Exca 200 unit, produces piles of uncrushed coal. These piles of uncrushed coal from the selective process are then immediately surveyed by the engineering team to calculate their volume. Following the survey, a joint assessment is conducted between the PT. MME quality control team and the PT. BSS mine operations team to determine whether the coal piles (uncrushed coal) are clean or not (Figure 5).

Figure 5. Manual Selective Sampling and Joint Assessment of Uncrushed Coal

Based on the sampling results at this research site, five piles of selective uncrushed coal products were sampled, with an average survey-calculated volume of 61.72 tons. Of the five sampled piles of selective uncrushed coal products, three piles passed the joint quality control assessment (free of batupack contaminants). Consequently, the effectiveness of batupack separation using this manual selective method was determined to be 60%, with an actual productivity of 36.6 tons/hour for contaminant-free selective product (Table 1). The selective product samples that did not pass the joint quality control assessment were subsequently subjected to re-selection. This inevitably results in additional costs borne by the company due to the need for repetitive work.

Table 1. Manual Selective Productivity

Description	Value
Average Sampling Tonnage	61.72 Tons
Selective work efficiency (based on assessment)	60
Productivity of the Manual Selective Method	36.6 tons/hour

Manual selective productivity depends on the level of precision or care exercised by the selective operators (handpickers and excavator operators) in identifying batupack within the pile. The identified batupack is then separated from the coal pile. Naturally, those directly involved in this selective activity need to be provided with detailed insight and knowledge regarding the differences between batupack and coal, as batupack and coal appear relatively similar to the naked eye. Therefore, this method is only effective during the day shift and is not performed during the night shift. This, of course, reduces the utilization of the selective process, which limits the production capacity of uncrushed coal.

The process of handling batupack using a bucket crusher excavator (BCE) essentially involves coal crushing and screening. The bucket crusher excavator loads coal that is still contaminated with batupack; this coal is then crushed, resulting in batupack-free coal after crushing and screening. Meanwhile, the uncrushed batupack is retained in the bucket crusher and subsequently separated from the pile of crushed coal. The bucket crusher excavator operation can be seen in Figure 6.

Figure 6. Bucket Crusher Excavator Operations

Field observations yielded data on equipment operating time and the bucket capacity of the bucket crusher excavator for each type or class, namely 20 tons, 30 tons, and 40 tons. Subsequently, by analyzing data on bucket crusher excavator constraints and equipment operating hours, the operational efficiency of the bucket crusher excavator was determined. The collected data was then processed to calculate the productivity of the bucket crusher excavator. The results of the coal crushing equipment productivity calculations are shown in Table 2 below.

Table 2. Productivity of the Bucket Crusher Excavator (BCE)

Description	**Value Based on Unit Class**		
	20 Tons (ZX200)	**30 Tons (ZX350)**	**40 Ton (ZX470)**
Equipment cycle time (seconds)	53.6 seconds	51.7 seconds	43.23 seconds
Bucket capacity	1.2 m^3	1.49 m^3	2.1 m^3
Work efficiency %	87%	89%	89%
BCE productivity	50 tons/hour	60 tons/hour	101 tons/hour

The analysis results show that the productivity of the bucket crusher excavator (BCE) is 50 tons/hour for the 20-ton model (ZX200), 60 tons/hour for the 30-ton model (ZX350), and 101 tons/hour for the 40-ton model. The productivity of the 30-ton BCE is not significantly higher than that of the 20-ton BCE due to the relatively small difference in bucket size. Several factors affecting the equipment's operational efficiency include secondary activities such as unit repositioning and batupack disposal. The operator's skill in operating the bucket crusher excavator unit plays a role in enhancing the equipment's operational efficiency. Crushed coal produced by the BCE can be transported directly without additional quality checks since it has undergone crushing and screening processes, and has been deemed contaminant-free by PT. BSS and PT. MME.

Handling Costs for Batupack Using the Manual Selective Method and the Bucket Crusher Excavator

Total equipment costs are divided into two components: ownership costs and operating costs. Ownership costs are annual fixed expenses, whether the equipment is in use or not. Meanwhile, operating costs only arise when the equipment is in operation (Gransberg et al., 2006) .

Ownership costs include calculations for depreciation, interest, insurance, and taxes. Based on the calculations in Table 3, the owning cost for an excavator unit used as a manual selective support tool is IDR 60,965 per hour. Based on the calculation of operating costs, which include fuel consumption, lubrication, oil, coolant, and major and minor spare part services (Table 4), for the use of one Exca 200 with support from one handpicker (daily casual worker), the operating cost for the manual selective method is IDR 353,584 per hour.

Table 3. Ownership Costs for the Manual Selective Method

Item	**Value**
Annual Rates	6%
Delivered Price (IDR)	IDR 1,620,600,000
Resale Value	10
Depreciated Value (IDR)	IDR 1,458,540,000
Equipment Lifespan (Years)	5
Equipment Lifetime (Hrs)	24,945 Hours
Depreciation Cost (IDR/Hr)	IDR 58,470 per Hour
Factor	64%
Interest, Insurance, and Tax (IDR/Hr)	IDR 2,495 per Hour
Ownership Cost (IDR per Hour)	**IDR 60,965 Per Hour**

Table 4. Operating Costs for the Manual Selective Method

Item Cost		Cost Per Hour	
A. Excavator Unit	Fuel	IDR	240,000
	Engine Oil	IDR	1,242
	Swing Machinery Oil	IDR	284
	Final Drive RH Oil	IDR	264
	Final Drive LH Oil	IDR	264
	Hydraulic Oil	IDR	3,575
	Coolant	IDR	122
	Grease	IDR	6,250
	Major Spare Parts Service	IDR	65,198
	Minor Parts Service	IDR	5,116
B. Operator	Operator Salary (1 Shift)	IDR	20,445
	Wage for 1 THL (1 Shift)	IDR	10,824
Total Operating Cost (IDR) Per Hour		**IDR**	**353,584**

The cost per ton incurred for separating batupack from coal using the manual selective method is (total owning cost + total operating cost) divided by productivity. Thus, the total cost incurred by the manual selective method is (IDR 60,965/hour + IDR 353,584/hour) ÷ 36.6 tons/hour = IDR 11,326/ton/hour.

The owning cost for the bucket crusher excavator method also includes calculations for depreciation, interest, insurance, and taxes. The initial new equipment price has been adjusted to account for the addition of the bucket crusher attachment for each class. Based on the calculations in Table 5, the owning cost is IDR 151,925 per hour for the 40-ton BCE unit (ZX470), IDR 127,975 per hour for the 30-ton BCE unit (ZX350), and IDR 76,870 per hour for the 20-ton BCE unit (ZX200).

Table 5. Ownership Costs for the Bucket Crusher Excavator (BCE) Method

Item	40-TON BCE (ZX470)		30-TON BCE (ZX350)		20-TON BCE (ZX200)	
Annual Rates		6%		6%		6%
Delivered Price	IDR	4,038,539,750	IDR	3,401,904,000	IDR	2,043,407,000
Resale Value						
Depreciated Value	IDR	3,634,685,775	IDR	3,061,713,600	IDR	1,839,066,300
Equipment Lifespan (Years)		5		5		5
Lifetime (Hrs)	IDR	24,945	IDR	24,945	IDR	24,945
Depreciation Cost (USD/Hr)	IDR	145,708	IDR	122,739	IDR	73,725
Factor		0.640		0.640		0.640
Interest, Insurance, and Tax (IDR per Hour)	IDR	6,217	IDR	5,237	IDR	3,146
Ownership Cost (IDR per Hour)	**IDR**	**151,925**	**IDR**	**127,975**	**IDR**	**76,870**

As for the operating costs, which include fuel consumption, lubrication, oil, coolant, and major and minor spare part services, they amount to IDR 846,661 per hour for the 40-ton BCE (Table 6), IDR 766,559 per hour for the 30-ton BCE (Table 7), and IDR 532,004 per hour for the 20-ton BCE (Table 8).

Table 6. Operating Costs of a 40-Ton Bucket Crusher Excavator

Item Cost		Cost per Hour	
a. Excavator Unit	Fuel	IDR	540,000
	Engine oil	IDR	2,970
	Transmission oil	IDR	4,209
	Steering & hoist oil	IDR	1,105
	Differential oil		
	LH Final drive oil	IDR	498
	RH Final drive oil	IDR	498
	Brake fluid		
	Coolant	IDR	1,281
	Grease	IDR	6,250
	Major Spare Parts Service	IDR	120,335
	Minor Spare Parts Service	IDR	12,687
b. Bucket Crusher	Spare Parts Service	IDR	115,938
c. Operator	Operator Salary (2 shifts)	IDR	40,890
Total Operating Cost (IDR) Per Hour		**IDR**	**846,661**

Table 7. Operating Costs for a 30-Ton Excavator Bucket Crusher

Item Cost		Cost per Hour	
a. Excavator Unit	Fuel	IDR	375,000
	Engine oil	IDR	1,944
	Transmission oil	IDR	2,460
	Steering and hoist oil	IDR	1,105
	Differential oil	IDR	1,721
	LH Final drive oil	IDR	419
	RH Final drive oil	IDR	419
	Brake Fluid		
	Coolant	IDR	672
	Grease	IDR	6,250
	Major Spare Parts Service	IDR	103,089
	Minor Parts Service	IDR	12,687
b. Bucket Crusher	Spare Parts Service	IDR	91,929
c. Operator	Operator Salary (2 shifts)	IDR	40,890
Total Operating Cost (IDR) Per Hour		**IDR**	**638,583**

Table 8. Operating Costs for a 20-Ton Excavator Bucket Crusher

Cost Item		**Cost per Hour**	
a. Excavator Unit	Fuel	IDR	240,000
	Engine Oil	IDR	1,242
	Swing Machinery Oil	IDR	284
	Final Drive Rh Oil	IDR	264
	Final Drive LH Oil	IDR	264
	Hydraulic Oil	IDR	3,575
	Coolant	IDR	122
	Grease	IDR	6,250
	Major Spare Parts Service	IDR	65,198
	Minor Parts Service	IDR	5,116
b. Bucket Crusher	Spare Parts Service	IDR	91,929
c. Operator	Operator Salary (2 shifts)	IDR	40,890
Total Operating Cost (IDR) Per Hour		**IDR**	**455,134**

As for the crushed coal product, additional revenue is generated based on the contracts between PT. BSS and PT. MME; therefore, the total cost per ton incurred for separating batupack from coal using the bucket crusher excavator method is calculated as (total ownership cost + total operating cost – revenue from crushed coal): productivity.

Table 9. Total Cost of Batupack Handling with a Bucket Crusher Excavator

Item	**BCE 40 Ton (ZX470)**	**BCE 30 Ton (ZX350)**	**BCE 20 Ton (ZX200)**
Ownership Cost (IDR)	151,925	127,975	76,870
Operating Cost (IDR)	846,661	638,583	455,134
Productivity (Tons/Hour)	101	60	50
Revenue from Crushed Coal (IDR/Ton)	7,000	7,000	7,000
Total Cost (IDR/Ton/Hour)	**2,887**	**5,776**	**3,640**

Based on the calculations, the cost is IDR2,886/Ton/Hour for a 40-ton bucket crusher, IDR5,776/Ton/Hour for a 30-ton bucket crusher, and IDR3,640/Ton/Hour for a 20-ton bucket crusher.

Strategy for Selecting a Batupack Handling Method

The method used to select the batupack handling method is the simple weighting method. Simple Additive Weighting (SAW) is a decision-making technique used to determine the best alternative from a number of options based on specific criteria. In selecting the batupack handling method, the criteria are divided into technical aspects with a weight of 50% and economic aspects with a weight of 50%. The technical criteria consist of productivity, work efficiency, utilization, and product output. The following are the suitability rating values for each alternative based on data analysis and calculations (Table 10).

Table 10. Suitability Rating Values for Each Batupack Handling Method Alternative

Alternative Code	**Alternative**	**Criteria**				
		Technical Aspects (50%)				**Economic Aspects (50%)**
		W1= Productivity (12.5%)	**W2 = Work Efficiency (12.5%)**	**W3 = Utilization (12.5%)**	**W4 = Product Output (12.5%)**	**W5 = Ownership and Operating Costs (50%)**
A1	MS 20 Ton	2	3	3	3	1
A2	BCE 20 Ton	2	5	5	5	4
A3	BCE 30 Ton	3	5	5	5	3
A4	40 BCE	5	5	5	5	4
Description		Weight 1 = 0–25 tons/hour Weight 2 = 26–50 tons/hour Weight 3 = 51–75 tons/hour Weight 4 = 76–100 tons/hour Weight = 101–125 tons/hour	Weight 1 = 0–20% Weight 2 = 21–40% Weight 3 = 41–60% Weight 4 = 61–80% Weight 5 = 81–100%	Weight 1 = 33% (<1 shift) Weight 3 = 34–66% (1 shift) Weight 5 = >66% (2 shifts)	Weight 1 = *Uncrushed Coal* (Lumps >75 cm) Weight 3 = *Uncrushed Coal* (<75 cm) Weight 5 = *Crushed Coal*	Weight 1 = IDR 10,001–12,500/ton/hour Weight 2 = IDR 7,501–10,000/ton/hour Weight 3 = IDR 5,001–7,500/ton/hour Weight 4 = IDR 2,501–5,000/ton/hour Weight 5 = IDR 0-2,500/ton/hour

Next, the normalization is calculated by dividing the rating value of each attribute column by the maximum value of each column, resulting in the decision matrix normalization values in Table 11 below:

Table 11. Normalization of the Decision Matrix for the Batupack Treatment Method

Alternative	**Criteria**				
	K1	**C2**	**C3**	**K4**	**C5**
A1	0.4	0.6	0.6	0.6	0.2
A2	0.4	1	1	1	0.8
A3	0.6	1	1	1	0.6
A4	1	1	1	1	0.8

The final process, which involves ranking the alternatives, is obtained by summing the results of multiplying the normalization matrix by the preference weights, as shown below:

A1 = (0.4)(0.125) + (0.6)(0.125) + (0.6)(0.125) + (0.6)(0.125) + (0.2)(0.5) = 0.375

A2 = (0.4)(0.125) + (1)(0.125) + (1)(0.125) + (1)(0.125) + (0.8)(0.5) = 0.825

A3 = (0.6)(0.125) + (1)(0.125) + (1)(0.125) + (1)(0.125) + (0.6)(0.5) = 0.75

A4 = (1)(0.125) + (1)(0.125) + (1)(0.125) + (1)(0.125) + (0.8)(0.5) = 0.9

Using the SAW method, the calculation results show the ranking order of each alternative, as presented in Table 12.

Table 12. Ranking Values of Alternatives for the Batupack Treatment Method

Alternative Code	Alternative	Preference Value	Rank
A1	20-Ton Manual Selective Excavator	0.375	4
A2	20-Ton Bucket Crusher Excavator	0.825	2
A3	30-Ton Bucket Crusher Excavator	0.75	3
A4	40-Ton Excavator Bucket Crusher	0.9	1

Based on the table above, the alternative with the highest score in the batupack handling method, based on technical and economic assessments, is the 40-ton bucket crusher excavator method with a preference value of 0.9. the second-highest score is for the 20-ton bucket crusher excavator with a preference score of 0.825, and the third-highest score is for the bucket crusher excavator with a preference score of 0.75, while the lowest score is for the manual selective batupack handling method with a preference score of 0.375.

CONCLUSION

Based on the preceding discussion, the following conclusions can be drawn:

1. The distribution pattern of batupack in coal seam D consists of lenses (spotty) in the body of coal seam D5 and layered (keybed) in the roof and floor of seam D5. Meanwhile, the distribution pattern of batupack in coal seam E consists of lenses (spotty) in the body of coal seam E2 and seam E3. The distribution pattern of batupack in coal seam F consists of layered (keybed) formations on the floor of coal seam F.
2. The productivity of the 20-ton manual selective system in producing clean coal (zero-contaminant coal) is 36.6 tons per hour. This is primarily influenced by the effectiveness of the identification and separation (selective) process of coal, which relies solely on visual inspection. Meanwhile, the productivity of the bucket crusher excavator (BCE) in producing clean coal (zero-contaminant coal) is 50 tons/hour for the 20-ton class (ZX200), 60 tons/hour for the 30-ton class (ZX350), and 101 tons/hour for the 40-ton class (ZX470). BCE productivity is influenced by bucket capacity and BCE operational efficiency. BCE operational efficiency can be improved by minimizing secondary BCE activities.
3. Based on a cost analysis, the handling cost for batupack was determined to be IDR 11,326/ton/hour for the 20-ton manual selective method, IDR 2,886/ton/hour for the 40-ton bucket crusher, IDR 5,776/ton/hour for the 30-ton bucket crusher, and IDR 3,640/ton/hour for the 20-ton bucket crusher.
4. Based on the strategic analysis of batupack handling activities using the simple additive weighting method, the highest value identified as the best option for batupack handling is the 40-ton bucket crusher excavator with a preference score of 0.9. The second-highest value was for the 20-ton bucket crusher excavator with a preference value of 0.825, and the third-highest value was for the 30-ton bucket crusher excavator with a preference value of 0.75. The lowest value was for the 20-ton manual selective batupack handling method with a preference value of 0.375.

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