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The Optimization of Production Costs of Overburden Removal and Coal Getting using Linear Programming Method

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Abstract

The problem that occurred at the research site was an increase in production targets in 2025, which caused the company to add heavy equipment units, directly impacting production costs, which needed to be minimized. This study aims to optimize production costs and analyze the impact of variable changes on the results of production cost optimization. The method used to obtain optimal costs is linear programming, utilizing the simplex approach with the aid of POM for Windows software. The optimization results show a decrease in production costs from IDR5,356,889,869 to IDR4,893,240,019 per month, or a savings of IDR463,649,850 per month, with a reduction of 9%, through a reduction in the number of working days without lowering production targets. Sensitivity analysis indicates that production constraints are the most influential factor on the optimal solution, while all decision variables play an active role. Some other constraints still have remaining capacity, indicating that the generated solution is efficient and optimal. The application of the linear programming method to minimize production costs has proven to achieve optimal production costs through the reduction of working days for each unit of loading and unloading equipment and transport equipment, and the variable most influencing the optimal solution is the production constraint.

Keywords: Simplex method; optimal solution; efficiency; sensitivity analysis; POM for Windows

1. Background

PT Garda Tujuh Buana Tbk is a holder of a Mining Business License (IUP) with coal commodities in Indonesia. Mining activities are carried out using an open mining system with the open-pit method. Open-pit mining is one of the methods that forms a large basin (usually cone-shaped) used to mine valuable material from shallow, large-scale, and non-selective deposits. This method involves gradual excavation in the form of slopes (benches) [1]. The company applies the open-pit method because coal is a deposit that has thick layers, and they need to create benches. The company divides the mining area into several blocks, and currently operations take place in the South Pit of the South Block. The mining process is carried out for 19 hours per day, divided into two shifts.

Mining operations are carried out by stripping and transporting the overburden and coal. This company uses various units of heavy equipment, such as excavators, dump trucks, and other supporting equipment. Based on conditions in the South Pit of the South Block of PT Garda Tujuh Buana Tbk, it can be seen that the equipment units operating for stripping overburden and coal are one unit of Sany 500 excavator, five units of Hitachi ZX 350 and one unit of Komatsu PC 300 with a combination of Hino 500 FM dump trucks, Hino 250 JD dump trucks and Hino 20 Ton dump trucks as many as 28 units.

Several types of costs are required to support the production process. Production costs include all costs incurred by a company to obtain production factors and resources to be managed by mining companies [2]. In this study, the costs incurred by the company are in the form of fuel usage costs, which include fuel for excavators Sany PC 500, Hitachi ZX 350 H, and Komatsu PC 300, fuel for dump trucks Hino 500 FM and Hino 250 JD, amounting to IDR 83,715,310.34/day for stripping and transporting overburden and coal. In addition to fuel costs, the costs incurred by PT Garda Tujuh Buana Tbk are equipment rental costs (contractor costs), costs incurred amounting to IDR 101,005,029.95/day in stripping and transporting overburden and coal.

In 2025, the company set a coal production target of 1.5 million tons/year, which is greater than the production target in the previous year, which was only 1.2 million tons/year. In the January 2025 period, PT Garda Tujuh Buana Tbk targets coal production of 49,663.27

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tons/month with an overburden volume reaching 360,952.07 BCM/month. The use of appropriate heavy equipment aims to achieve the set production targets. Production that does not reach the target can increase production costs. Owing to an increase in production targets in 2025, the company even added heavy equipment units, which had a direct impact on high daily operating costs. If not controlled, this increase in targets can reduce profit margins.

To address the problem of high production costs incurred for overburden and coal stripping, a technical and economic study is needed to minimize production costs to maximize profits by optimizing [3,4]. Optimization in mining activity is a systematic approach that aims to improve operational efficiency and reduce costs [5]. The appropriate optimization method to be applied in this study is the linear programming method, which is a mathematical approach used to determine the optimal allocation of resources, especially in conditions of limited resources owned by an entity or company [6]. This method is one of the most commonly applied optimization techniques and is known to be one of the most effective approaches in quantitative-based decision-making [7]. In this study, there are more than two variables; therefore, the use of the simplex method in linear programming is the most effective, as explained by [8], who stated that the simplex method is an effective algorithm for solving problems in linear programming. The simplex method helps optimally organize resources, reduce costs, and increase profits; therefore, it is the most appropriate method for minimizing production costs.

This study was conducted to minimize the production costs incurred in the overburden and coal stripping processes to increase profit margins.

2. Research Method

This study employs a quantitative approach, a research method that is conducted systematically to understand a phenomenon through the collection of measurable data [9]. In the context of this study, the quantitative approach focuses on optimizing production costs and analyzing the factors that most influence the optimization results owing to changes in variables. Thus, the results of this study can provide a clear and measurable picture of the efficiency and effectiveness of production costs.

One approach used to assess the efficiency and cost-effectiveness of production is through linear programming optimization [4]. This method is used to solve optimization problems in linear mathematical models, taking into account various resource constraints. The process of optimizing production costs using linear programming with the simplex approach is an appropriate alternative for the purpose of optimizing production costs in overburden and coal stripping activities [10].

Data processing was performed using Microsoft Excel and POM for Windows software. The POM for Windows program is a computer program used to solve quantitative problems in the field of production and operations management [11].

This study aims to optimize production costs in overburden removal and coal getting using the linear programming method. The background of this study is the increase in production targets in 2025, which has prompted the company to add heavy equipment units, thereby increasing the production costs. To address this issue, data related to equipment and operations, such as cycle time, number of machines, efficiency, working hours, rental costs, and fuel expenses, were collected. These data were then used to develop a mathematical model consisting of an objective function (cost minimization) and constraint functions. Optimization was performed using the simplex method via the POM for Windows software. The results of this process include the optimal production cost solution and sensitivity analysis to identify the variables most influential on the optimization outcomes, thereby achieving the most efficient production cost under constrained conditions. The following is a research flowchart, as shown in Fig. 1.

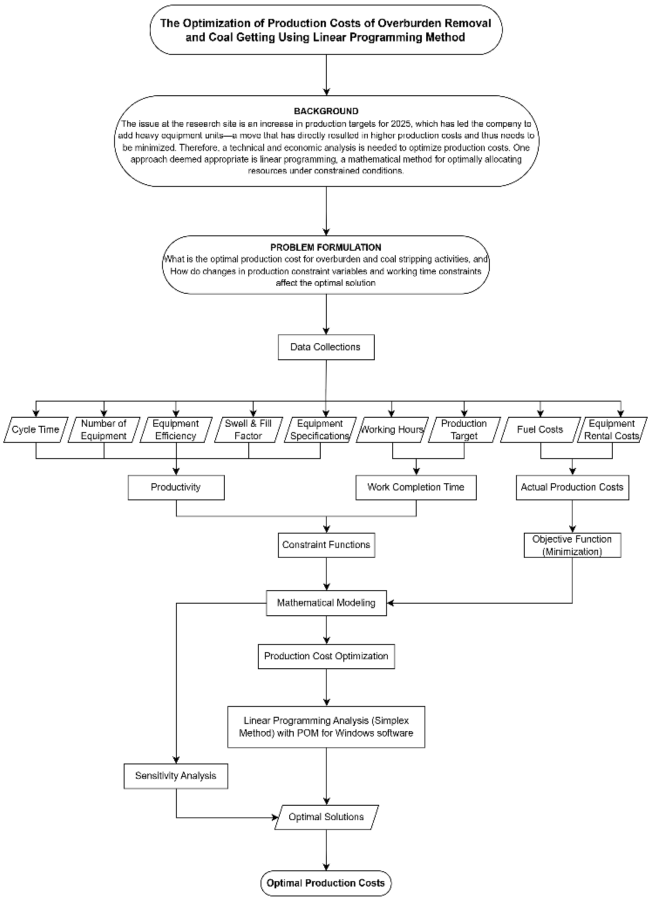

Figure 1. Research flowchart

3. Results and discussion

3.1. Data collections

Some of the data that has been collected during the research process are as follows:

a. Fuel cost, which includes fuel from transport equipment and loading and unloading equipment during production. The fuel costs are presented in Table 1.

Table 1. Equipment fuel costs

Unit	n	Fuel issued (Liter/days)	Fuel cost (IDR/days)
Sany 500	1	477.58	5,966,551.72
Hitachi ZX 350H	5	2,397.09	24,663,517.24
Komatsu PC 300	1	532.70	7,920,758.62
DT HINO 500 FM	4	1,146.50	6,493,034.48
DT HINO 250 JD	20	5,770.20	31,609,448.28
DT HINO 20 ton	4	1,254.10	7,062,000.00
Total	35		83,715,310.34

b. Rental costs are incurred in the form of equipment rental costs used during production operations. The following are the details of the costs incurred by the company per month. The equipment rental costs are presented in Table 2.

Table 2. Equipment rental costs

Unit	n	Fuel cost (IDR/days)
Sany 500	1	480,000.00
Hitachi ZX 350H	5	612,672,000
Komatsu PC 300	1	178,752,000
DT HINO 500 FM	4	1,400,729,913
DT HINO 250 JD	20	286,799,955
DT HINO 20 Ton	4	300,000,000
Total	35	101,005,029.95

The total production cost is a combination of fuel costs and rental unit costs. These two costs are incurred by the company during the production process, as shown in Table 3.

Table 3. Total actual production costs

Fleet	Costs excavator /days (IDR)	Costs DT/days (IDR)	Days	Total costs/fleet /days (IDR)
DT HINO 500 FM and Excavator Sany 500	11,145,586.21	16,382,688.11	29	798,319,955.20
DT HINO 250 JD and Excavator Hitachi ZX 350 H	45,790,137.93	79,910,479.77	29	3,645,317,913.38
DT HINO 20 Ton and Excavator Komatsu PC 300	14,084,620.69	17,406,827.59	29	913,252,000.00
		Total		5,356,889,868.58

c. Working hours at the research site are divided into two shifts, each with a total of 9.5 hours per shift, and there are 19 hours in a day. The following is a breakdown of the working hours, as shown in Table 4.

Table 4. Working hours

Schedule hours	Month date		Units	January
	Number of days		days	31
Calender	Available shift		shift	62
	Available hours		hours	744
Lost Day	Public holiday		day	0.5
	Every public holiday		shift	1
Lost Shift	Overshift	1	Sunday shift 1	2.5
	Total		shift	3.5
Lost Hours	Public holiday + Overshift		hours	42
	Real Available Hours		hours	702
Idle Time	Rain and slippery		hours	126.00
	Change shift	1	hours/shift	58.50
	Briefing (PSM)	0.25	hours/shift	14.63
	Safety talk every Tuesday	0.5	hours/shift	5.00
	Daily inspection and checking	0.17	hours/shift	9.75
	Prepare location	0.25	hours/shift	14.63
	Rest and a meal	1	hours/shift	58.50
	Praying Friday	1	hours/shift	4.00
	Fasting break (Ramadhan)	1	hours/shift	
	Total		hours	291.01
Available for Work	Working days		day	30.5
	Working shift		shift	58.5
	Equipment availability hours (MA) Before Physical of Availability (PA)	90%	%	410.99
	Assumptions (maintenance+break)		hours	41.10
	Working hours elective		hours	369.89
	Utilization of Availability (UA)		%	55.96769
Coal Getting	Loss shift	1	every night shift	
	Lost time at the starting shift	0.5	hours/shift	29.25
	Closing the weight bridge	0.5	hours/shift	29.25
	Total lost time		hours	58.50
	Working hours elective		hours	317.25
	Utilization of Availability (UA)		%	47

d. The production and target production of equipment units are the production target data and coal overburden production in January 2025, as shown in Table 5.

Table 5. Production and target production

Unit	Production (BCM/days)	Targets (BCM/month)
x_1	2,339.45	60,325.55
x_2	12,815.93	303,663.10
x_3	2,329.41	68,233.03

This study produced a production cost optimization model by considering a combination of excavation and transportation equipment. Three combinations of equipment were analyzed:

Fleet 1: Sany 500 Excavator & Hino 500 FM Dump Truck
Fleet 2: Hitachi ZX 350 Excavator & Hino 250 JD Dump Truck
Fleet 3: Komatsu PC 300 Excavator & Hino 20 ton Dump Truck

3.2. Equipment productivity

The productivity of the calculated equipment includes the productivity of the digging-loading equipment and hauling equipment, where the aim is to determine the amount of production of each tool that works during the overburden and coal stripping process. The results of the productivity calculations for the excavating and transporting equipment are presented in Table 6.

Table 6. Working hour constraint coefficient

Units	Excavator productivity (BCM/hour)	DT productivity (BCM/hour)	Production (BCM/days)
x_1	206.27	75.59	2,339.45
x_2	1,067.72	357.45	12,815.09
x_3	202.59	72.72	2,329.41

3.3. Optimization of production cost

Mathematical modeling is the process of translating real-world problems into mathematical models to analyze, simulate, and solve them using mathematical methods. The goal is to understand, predict, or optimize a system or process using mathematical tools.

a. Decision variable
The decision variable of the production cost optimization process in overburden and coal stripping using this linear programming method is the optimal number of dump trucks for excavators. The optimal number of dump trucks from the optimization results affects the production costs of overburden and coal stripping. The overburden and coal stripping activities use Sany 500, Hitachi ZX 350 H, and Komatsu PC 300 excavators and hauling equipment in the form of DT HINO 500 FM, DT HINO 250 JD, and DT HINO 20 Ton. Therefore, the linear programming analysis in this study has three decision variables for each fleet of equipment that work, among others. For example:

x_1: Number of working days DT HINO 500 FM with Excavator Sany 500
x_2: Number of working days DT HINO 250 JD with Excavator Hitachi ZX 350 H
x_3: Number of working days DT HINO 20 Ton with Excavator Komatsu PC 300

b. Objective function
The objective function, which is the objective to be achieved in this study, is to minimize the production costs in overburden and coal stripping activities. Based on the data obtained, the production cost for the combination of Excavator Sany 500 and DT HINO 500 FM in fleet 1 was IDR27,528,274.32, for the combination of Excavator Hitachi ZX 350 H and DT HINO 250 JD in fleet 2 was IDR125,700,618, and for the combination of Excavator Hitachi ZX 350 H and DT HINO 20 Ton in fleet 3 was IDR31,491,448.28. These costs are the costs incurred for the overburden and coal stripping processes per day. The equation formed to optimize production costs in overburden and coal stripping activities is expressed in Equation 1.

$$\text{Min } Z = C_1x_1 + C_2x_2 + C_3x_3 \quad (1)$$

where,
C_1: Production costs on DT HINO 500 FM and Sany 500 Excavator
C_2: Production costs on DT HINO 250 JD and Hitachi ZX 350 H Excavator
C_3: Production costs on DT HINO 20 Ton and Komatsu PC 300 Excavator

then:

$$\text{Min } Z = 27{,}528{,}274x_1 + 125{,}700{,}618x_2 + 31{,}491{,}448x_3 \quad (2)$$

c. The constraint function is an important component that describes the real constraints or conditions that must be met in the production process. This function is used to limit the solution space to remain in accordance with the real-world conditions. The constraint functions in the linear programming analysis are as follows:
1) Work completion time constraints; the working hour constraints used in this optimization process are the available working hours in January for overburden and coal stripping. The available working hours per day for production were 19 hours, with 29 working days in January. The coefficient used in the working hour constraint function is the calculation of effective working hours for production per month divided by the total overburden production per month for each unit. The results of the working hour constraint function coefficient calculation can be seen in Table 7.

Table 7. Working hour constraint coefficient

Units	Effective working hours (Month)	Target production (BCM / Month)	Coefficient
x_1	1,150	38,313.38	0.0300
x_2	5,254	131,563.31	0.0339
x_3	1,150	38,913.30	0.0296

This working hour constraint becomes a limiting reference for how the production process is in accordance with effective working hours to achieve the production target. The inequality form for the constraint function of working hours can be expressed as follows (inequality 3):

$$0.0300x_1+0.0339x_2+0.0296x_3 \leq 29 \quad (3)$$

2) Production constraints; actual production based on field observations in fleet 1 there are four conveyances working with a representative of one DT unit resulting in a conveyance cycle time of 23.57 minutes with a distance from fleet loading to disposal of 1.15 km and a productivity value of 2,339.45 BCM/day, in fleet 2 has 20 units of conveyance with a representative of one DT unit resulting in a conveyance cycle time of 24.92 minutes with a distance from fleet loading to disposal of 1.22 km and a productivity value of 12,815.93 BCM/day, in fleet 3 has four units of conveyance with a representative of one DT unit resulting in a equipment cycle time of 24.50 minutes and a productivity value of 2,329.41 BCM/day with a distance of 1.09 km to disposal. The inequality function of the productivity constraint is expressed in the following equation

a) Production of Sany500 and DT HINO 500 FM

$$2,339.45\ x_1 \geq 60,325.55 \quad (4)$$

b) Production of Hitachi ZX 350 H and DT HINO 250 JD

$$12,815.93\ x_2 \geq 303,663.1 \quad (5)$$

c) Production of Komatsu PC 300 and DT Hino 20 Ton

$$2,329.41\ x_3 \geq 68,233.03 \quad (6)$$

3) Non-negative constraints; this constraint represents the amount of production costs in overburden and coal stripping that cannot be negative. The form of the inequality can be expressed in Equation 7.

$$x_1, x_2, x_3 \geq 0 \quad (7)$$

3.4. Linear programming using the simplex method

The results of the linear programming analysis using the simplex method showed that the iteration stopped at the 5th iteration count. Iteration is the process of repeating the same steps several times until the best or most appropriate result is obtained. Each repetition is called one iteration, and the result of the previous step is usually used for the next step. This is due to the Zj - Cj row in the decision variable column, and slack has reached a value of 0, which indicates that the solution is optimal, as shown in Table 8.

Table 8. Results of the 5th iteration calculation

Cj	VB	27,528,274.32	125,700,617.70	31,491,448.28	0	0	0	0	0	0	0	0	0	Q
		X1	X2	X3	Artfcl 1	Surplus 1	Artfcl 2	Surplus 2	Artfcl 3	Surplus 3	Slack 4	Artfcl 5	Surplus 5	
0	X1	1	0	0	0.0007	-0.0007	0	0	0	0	0	0	0	266,784
0	X2	0	1	0	0	0	0.0001	-0.0001	0	0	0	0	0	259,386
0	X3	0	0	1	0	0	0	0	0.0007	-0.0007	0	0	0	281,654
0	S'4	0	0	0	0	0	0	0	0	0	1	0	0	264,866
0	S5	0	0	0	0	0	0	0	0	0	0	-1	1	0
zj		0	0	0	2	0	2	0	2	0	0	2	0	0
cj-zj		0	0	0	-1	0	-1	0	-1	0	0	-1	0	

Table 9. Production cost optimization results on the POM for Windows software

	X1	X2	X3		RSH	Dual
Minimize	27.528.270	125,700,600	31,491,450			
Production 1	1,436.12	0.0000	0	≥	38,313.38	-19,168.50
Production 2	0	7,384.21	0	≥	191,536.30	-17,022.89
Production 3	0	0	1,381.60	≥	38,913.30	-22,793.46
Work completion time	0.0300	0.0339	0.0296	≤	29	0
Non-negative constraint	0	0	0	≥	0	0
Solution	26.6784	25.9386	28.1654		4,881,881,000	0

Once the iteration stops, the analysis process produces an optimal solution based on the existing constraints. The results of the linear programming analysis (optimal solutions) are shown in Table 9.

In accordance with the predetermined decision variables, namely to determine the optimal number of dump trucks for excavators, the results of the linear programming analysis (Table 9) show that the number of working days for dump trucks and excavators has decreased, resulting in lower costs for overburden and coal production. This reduction in the number of working days was due to more efficient scheduling and allocation of equipment. The reduction in the number of working days occurred in fleet 1, which uses Sany500 excavators and HINO 500 FM dump trucks, from 29 days to 27 days. Fleet 2, which uses Hitachi ZX 350 H excavators and

HINO 250 JD dump trucks, also decreased from 29 days to 26 days, and Komatsu PC 300 excavators and 20-ton HINO dump trucks decreased from 29 days to 28 days. This combination enables the achievement of production targets with fewer working days, owing to high productivity with the maximum number of units operated. Additionally, the use of optimization methods, such as linear programming, enables the company to reduce expenses without compromising production targets. A comparison of the number of working days for each type of heavy equipment is shown in Fig. 2.

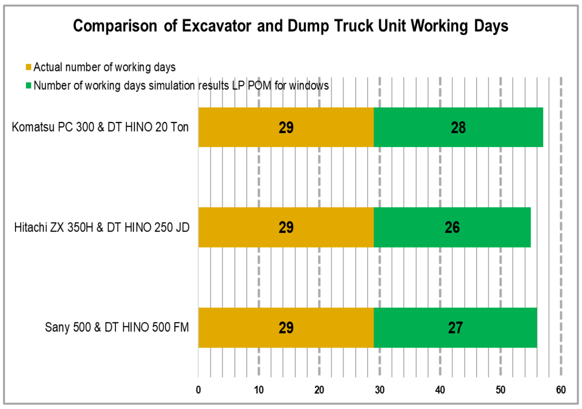

Figure 2. Comparison of the number of working days

The use of POM for Windows software showed a difference between the actual number of working days and the simulation results, where the simulation results showed a lower number of working days in accordance with the predetermined decision variables. This condition was caused by the high level of productivity of each tool combination. High productivity allows fieldwork to be completed more quickly, resulting in more efficient working hours. This supports the reduction of overall production costs.

After linear programming analysis using POM for Windows, the optimal production cost for overburden and coal stripping was obtained as shown in Table 10.

Table 10. Production cost after optimization using the linear programming method on the POM For Windows software

Fleet	Costs excavator/days (IDR)	Costs DT/days (IDR)	Days	Total costs/Fleet /days(IDR)
x_1	11,145,586.21	16,382,688.11	27	743,263,406.56
x_2	45,790,137.93	79,910,479.77	26	3,268,216,060.27
x_3	14,084,620.69	17,406,827.59	28	881,760,551.72
		Total		4,893,240,018.56

The optimization results based on Table 10 show that the optimal production cost obtained is IDR4,893,240,018.56 ≈ IDR4,893,240,019 per month. This value shows a significant decrease compared to the company's actual production costs, which amounted to IDR5,356,889,868.58 ≈ IDR5,356,889,869 per month, with an efficiency difference of IDR463,649,850.02 ≈ IDR463,649,850 per month and a percentage decrease of 9%.

The resulting production cost is said to be optimal because it has undergone an iterative mathematical process in the simplex method of linear programming, ensuring that no other combination of decision variables can yield a lower cost while still satisfying all constraints. Based on the analysis results in Table 10, the iteration calculation stopped at the fifth iteration, as indicated by the values in all Cj-Zj rows reaching a value of ≤ 0 (i.e., negative or equal to zero). This condition indicates that additional iterations will not produce a better (more minimal) solution than the current solution. This efficiency not only reduces cost burdens but also contributes to improving the overall profitability of the company.

The decrease in production costs is influenced by the efficiency of the working days of the excavator and dump truck units used for overburden and coal stripping. Actually, the unit operates for overburden and coal stripping activities for 29 days as scheduled, but after optimization to minimize costs, it was found that the number of working days required decreased in fleets 1 and 2. This reduction indicates that there are excess working days under actual conditions that do not contribute optimally to production. To clearly observe the level of decline in production costs before and after optimization, as shown in Fig. 3.

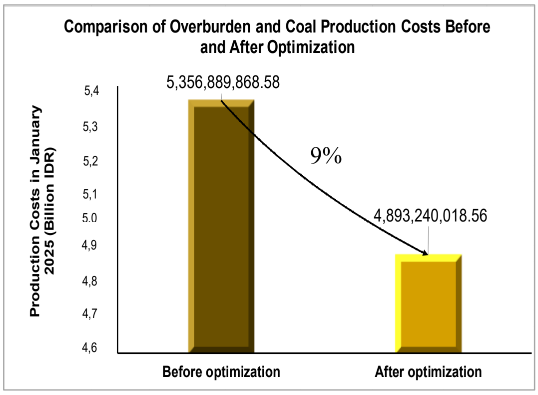

Figure 3. Comparison of actual production costs and production costs after optimization using the linear programming method

3.2 Sensitivity analysis

Sensitivity analysis of the production cost optimization results in POM for Windows software aims to understand how changes in certain parameters affect the optimal solution. To observe the changes, we can see the optimal solution value, reduced cost, slack/surplus, lower bound, and upper bound. The results of the sensitivity analysis of the optimization results of the overburden and coal stripping production costs are shown in Table 11.

Based on Table 11, the sensitivity analysis of the optimization results shows the optimal value for three decision variables (x_1, x_2, and x_3), namely x_1 = 27 (rounding) x_2 = 26 (rounding) and x_3 = 28 (rounding) The three variables have a Reduced Cost of 0, indicating that all variables contribute actively to the optimal solution. Then, in the objective function, the value (Original Value) is respectively for x_1 of 27,528,270, x_2 of 125,700,600, and x_3 of 31,491,450 with a Lower Bound of 0 and an Upper Bound of infinity, indicating that there is no explicit upper limit on the value of each variable.

Table 11. Sensitivity analysis results of overburden and coal stripping production cost optimization

Variable	Value	Reduced Cost	Original Value	Lower Bound	Upper Bound
X1	26.6784	0	27,528,270.00	2	Infinity
X2	25.9386	0	125,700,600.00	0	Infinity
X3	28.1654	0	31,491,450.00	0	Infinity
Constraint	Dual Value	Slack/Surplus	Original Value	Lower Bound	Upper Bound
Production 1	-19,168.50	0	60,325.55	0	1,306,246
Production 2	-17,022.89	0	303,663.10	(-0)	5,960,943
Production 3	-22,793.46	0	68,233.03	0	1,275,195
Work completion time	0	26.4866	29	2.5143	Infinity
Non-negative constraints	0	0	0	Infinity	0

The results of the sensitivity analysis of each constraint in this study show a variety of variations such as the work completion time constraint with an unlimited upper limit value and a lower limit of 2.5134 which means that the work completion time can be reduced by 26.4866 hours (actual work time minus the lower limit value of 2.5134 hours) with a dual value of 0, indicating that changes in the limits and lower limits on this constraint do not affect the optimal solution, and this constraint is not active (non-binding).

In contrast to the work completion time constraints, production constraints include the production of the Sany 500 and DT HINO 500 FM (x_1), the Hitachi ZX 350 H and DT HINO 250 JD (x_2), and the Komatsu PC 300 and DT Hino 20 Ton (x_3), these three variables actually have a considerable influence on the optimal solution of each. Production constraint for the Sany 500 and DT HINO 500 FM, had a lower limit value of 0.0039 and an upper limit of 1,306,246, indicating that production could be increased. While the production constraints for the Hitachi ZX 350 H and DT HINO 250 JD, the lower limit value is -0.0156 with an unlimited upper limit of 5,960,943, which means that production can be increased.

In production constraint of the Komatsu PC 300 and DT Hino 20 Ton equipment, the lower limit value is 0.0039 with an upper limit value of 1,275,195, which means production can be increased, and the slack/surplus value is equal to 0, this shows that this constraint is active (binding), or fully used. The dual value for the production of tool x_1 is (-19,168.5), the production of tool x_2 is (-17,022.89), and the production of tool x_3 is (-22,793.46). These negative values indicate that an increase in the right-hand side of the constraint will increase the objective function value, as this is a minimization problem. In economics, this dual value can be interpreted as the shadow price, which is the change in the objective function value if there is an additional resource. The last constraint is a non-negative constraint with a slack value of 0, indicating that the variables are at their lower bounds (0 or more).

4. Conclusions

Based on the optimization results, the optimal production cost was IDR4,893,240,018.56 ≈ IDR4,893,240,019, which is 9% lower than the actual production cost of IDR5,356,889,868.58 ≈ IDR5,356,889,869 in January 2025. This efficiency reflects cost savings of IDR463,649,850.02 ≈ IDR463,649,850 achieved through adjustments to the number of working days for dump trucks and excavators without compromising production targets. These results demonstrate that the mathematical optimization model can identify unproductive excess capacity and generate more efficient operational decisions. The obtained cost is also considered optimal because no other combination of variables yields a lower result while all system constraints remain satisfied. Meanwhile, the sensitivity analysis conducted shows that the constraints most influential on the optimal solution are production constraints 1, 2, and 3. This is indicated by significant dual values and slack values of zero, indicating that these three constraints are active (binding) and fully utilized for the optimal solution in this study. Meanwhile, decision variables $x1$, $x2$, and $x3$ all play an active role in the optimal solution, as seen from the reduced cost value of zero, which indicates that the presence of these three variables is necessary to achieve the optimal solution.

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