

Mining Sequence Compliance and Production Performance in an Open-Pit Coal Mine: A Case Study of Pit Rista, South Sumatra

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ABSTRACT

This study assesses coal and overburden production efficacy for the mining sequence at Pit Rista, PT Dewa Sukses Mandiri, South Sumatra, during July and August 2025, and recommends operational enhancements to facilitate production objectives in the following months. The investigation was prompted by the inability to meet monthly production targets, as evidenced by insufficient effective working hours, excessive downtime, low equipment availability, and discrepancies between planned and actual mining progress. A quantitative evaluative method was employed utilizing primary data consisting of loading and hauling cycle durations, alongside secondary data such as production reports, working hours, downtime records, mine design, and mining sequence plans. The examination encompassed equipment productivity, job efficiency, match factor, physical availability (PA), use of availability (UA), Pareto analysis of downtime, and a comparison between planned and actual implementation of the mining sequence. The findings indicate that production deficits in July and August 2025 were mostly attributable to diminished effective working hours resulting from operational and mechanical delays, low PA and UA values, and discrepancies between the planned mining sequence and actual field execution. In July, the primary cause of lost time was the lack of hauling help, however in August, weather-related delays emerged as the principal limitation. These conditions impeded mining advancement and diminished overall output efficacy. In light of these findings, production optimization should prioritize enhancing mining sequence execution, reinforcing equipment maintenance and oversight, reconfiguring pit front and haul road geometry, and regulating haul road gradients to minimize downtime and enhance operational efficiency.

Keywords

Mining sequence; equipment productivity; equipment availability; downtime; production optimization

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INTRODUCTION

Achieving production targets is a central requirement in open-pit coal mining because the continuity of material extraction, equipment utilization, and haulage flow directly determines operational efficiency and economic performance. In this context, production scheduling and short-term mine planning are not only technical planning tools but also operational controls that determine whether coal and overburden can be extracted in accordance with production objectives [1], [2]. Recent studies further emphasize that the success of open-pit operations depends on the degree to which field execution remains aligned with the mine plan, particularly at the short-term planning level where mining sequences are physically implemented in the pit [3], [4].

At the operational level, production performance is strongly affected by how well mining sequences are translated into executable working fronts, haulage routes, and equipment deployment. When sequencing is not implemented in accordance with pit design, the result is often delayed mine progress, unbalanced stripping activities, and lower production achievement. In addition, equipment-related factors such as availability, utilization, and productivity play a decisive role in determining whether planned production can actually be realized [5]–[7]. Studies on mine scheduling and pit design also indicate that proper sequencing must consider field progress, equipment capacity, road access, and production control so that each mining stage can be executed effectively and safely [3], [8].

Production shortfalls in open-pit mining are rarely caused by a single factor. Instead, they usually arise from the interaction between limited effective working hours, high loss time, equipment downtime, low equipment utilization, and unfavorable operating conditions. Previous local studies in Indonesian mining operations have shown that cycle time, work efficiency, match factor, and equipment availability significantly influence loading and hauling productivity, while low physical availability can directly reduce production achievement [9], [10]. Supporting operational conditions are also important. Maintenance performance affects equipment readiness and repair time, while haul road geometry and gradient influence truck movement, resistance, and operational efficiency [11], [12]. These findings show that production performance must be evaluated as an integrated operational system rather than as isolated technical indicators.

However, the existing literature still tends to examine mine planning, equipment performance, and working-time efficiency separately. Some studies focus on optimizing production scheduling [1], [2], others emphasize mine-to-plan compliance [3], pit sequencing concepts [8], or equipment effectiveness and availability [5]–[7], [10], while fewer studies evaluate how these variables interact in actual field implementation at an operating pit. In particular, limited attention has been given to the combined effect of mining-sequence deviation, low effective working time, loss time, and PA–UA performance on both coal and overburden production achievement within the same production period. This gap is important because monthly production failure in contractor-based coal mining is typically the result of simultaneous planning and operational inefficiencies.

Such conditions were observed at Pit Rista, PT Dewa Sukses Mandiri, South Sumatra, where coal and overburden production targets for July and August 2025 were not achieved. Preliminary operational records indicated low effective working hours, high loss time, low physical availability (PA) and use of availability (UA), and deviations between the planned mining sequence and actual field progress. These conditions disrupted the balance between overburden stripping and coal exposure and reduced overall mine progress during the study period.

Accordingly, this study addresses three research questions: (1) how did the implementation of the mining sequence affect the achievement of coal and overburden production at Pit Rista; (2) what factors most strongly contributed to production inefficiency during July and August 2025; and (3) what technical and operational improvements can be proposed to improve production performance in the following months? To answer these questions, the study evaluates production achievement by comparing planned and actual data, analyzes equipment performance through productivity, PA, and UA indicators, and assesses the conformity between actual field progress and the planned mining sequence. The study is expected to contribute both practically and analytically by providing an integrated evaluation of mining-sequence implementation, equipment performance, and effective working time as a basis for short-term production optimization in open-pit coal mining.

METHOD

Research Design

This study employed an applied quantitative approach to evaluate the causes of failure to achieve coal and overburden production targets at Pit Rista, PT Dewa Sukses Mandiri, during July and August 2025. The analysis focused on production achievement, equipment performance, working-time efficiency, loss time, and the conformity between the planned mining sequence and actual field implementation. The final objective was to formulate operational improvement measures for the production period from September to December 2025. This type of evaluative analysis is consistent with recent mine-operation studies that use cycle time, productivity, utilization, and operational time classifications as the basis for diagnosing production bottlenecks and improving field performance [13]–[18].

Study Area

The study was conducted at Pit Rista, operated by PT Dewa Sukses Mandiri within the Mining Business License (IUP) area of PT Bara Mutiara Prima, located in Sri Gunung Village, Sungai Lilin District, Musi Banyuasin Regency, South Sumatra Province. Geographically, the site is located at approximately $2^{\circ}30.685' S$ and $103^{\circ}59.815' E$. Figure 1 presents the location of the IUP area and the position of the study site within the mining concession.

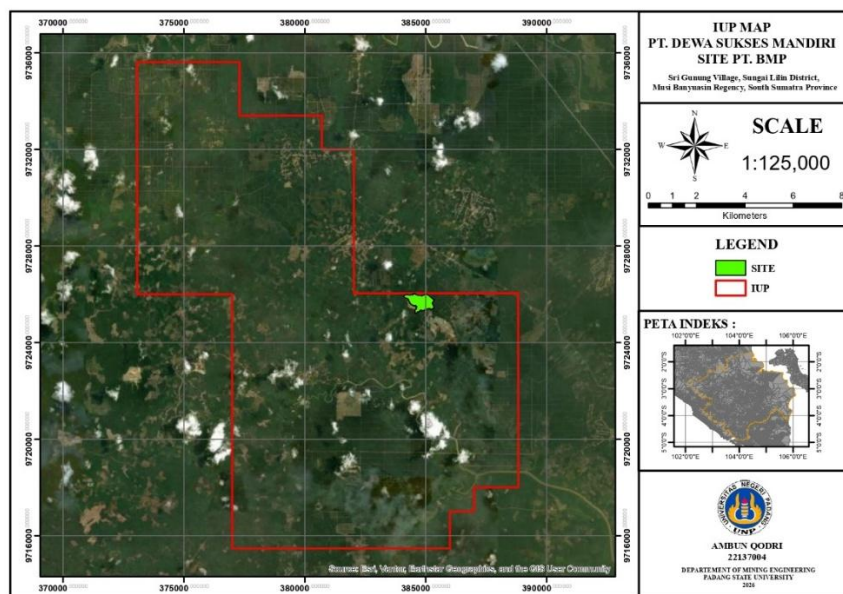


Figure 1. The Mining Business License of PT Dewa Sukses Mandiri

Geologically, the research area is part of the South Sumatra Basin. The site is associated with the Muara Enim Formation (TMPM), which is widely recognized as one of the principal coal-bearing units in the basin. As shown in Figure 2, the Pit Rista area lies within the mapped extent of this formation, which forms the geological basis of the coal mining activities evaluated in this study [13].

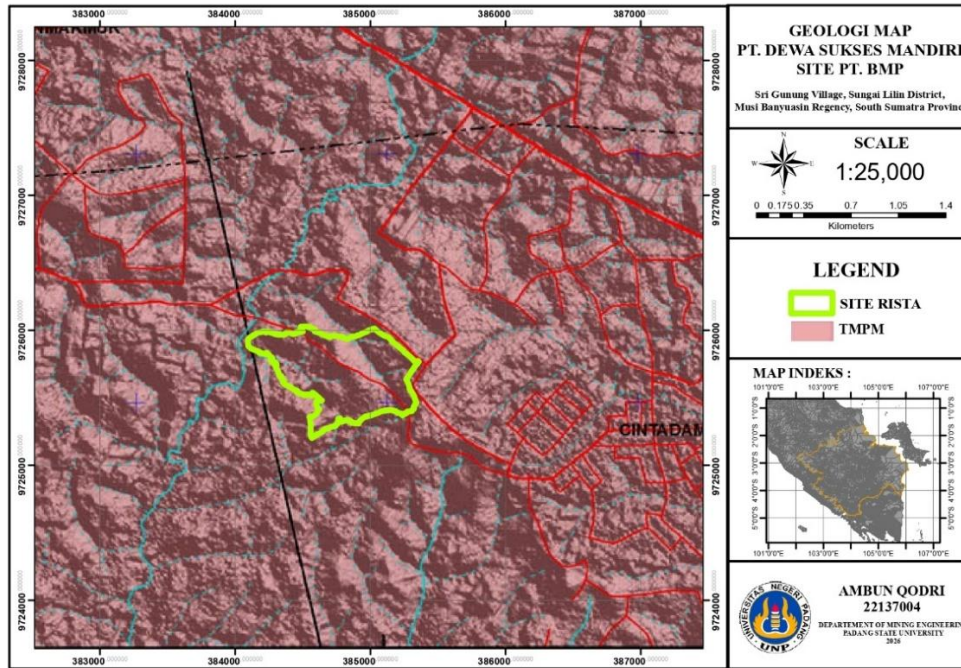


Figure 2. Geological Map of PT. Dewa Sukses Mandiri

Data Collection

This study used both primary and secondary data. Primary data consisted of direct field observations in the form of cycle time measurements for loading and hauling equipment operating during the July–August 2025 production period. Secondary data were obtained from company records and included production targets, actual production reports, working-hour reports, loss-time records, physical availability (PA), use of availability (UA), end-of-month (EOM) topographic data, mine design, mining sequence plans, rainfall records, geotechnical recommendations, haul-road recommendations, and equipment specifications.

Rainfall data were included because weather conditions directly affect road surface condition, front accessibility, and effective working hours in open-pit operations, particularly during wet periods [14]. The combination of primary time-study data and secondary operational records is appropriate for production-evaluation studies because it enables simultaneous assessment of equipment performance, operational constraints, and mine progress [15], [16].

Research Variables

The variables analyzed in this study are summarized in Table 1, which presents the research variables, indicators, data sources, and analytical methods. The main variables included: (1) coal production, (2) overburden production, (3) loading cycle time, (4) hauling cycle time, (5) equipment productivity, (6) working efficiency, (7) physical availability (PA), (8) use of availability (UA), (9) loss time, (10) mining-sequence compliance, (11) haul-road geometry, and (12) rainfall.

Table 1. Data conclusions

No	Variable	Indicator	Data Source	Analysis Method
1	Coal Production	Actual vs target tonnage	Secondary data	Actual vs planned comparison
2	Overburden Production	Actual vs target volume (BCM)	Secondary data	Actual vs planned comparison
3	Hauling Equipment Cycle Time	Cycle time (minutes)	Primary data	Average cycle time calculation
4	Loading Equipment Cycle Time	Cycle time (minutes)	Primary data	Average cycle time calculation
5	Equipment Productivity	Output per hour (tons/hour or BCM/hour)	Primary & secondary data	Equipment productivity calculation
6	Working Efficiency	Effective working time (%)	Secondary data	Working efficiency calculation
7	Physical Availability (PA)	Equipment availability percentage (%)	Secondary data	PA calculation
8	Use of Availability (UA)	Equipment utilization percentage (%)	Secondary data	UA calculation
9	Loss Time	Operational lost time (hours)	Secondary data	Pareto analysis
10	Mining Sequence	Compliance with mine design	Secondary data	Comparative descriptive analysis
11	Haul Road Geometry	Grade, road width	Secondary data	Technical evaluation
12	Rainfall	Rain intensity (mm)	Secondary data	Descriptive analysis

Table 1 functions as the variable matrix of the study and shows that the evaluation was not limited to production output alone, but also considered supporting operational indicators affecting monthly mine performance. In this way, the analysis linked production achievement with equipment condition, working time, road conditions, and implementation of the mining sequence.

Data Analysis Procedures

The analytical workflow used in this study is illustrated in **Figure 3**. As shown in the flow chart, the study began with literature review, field observation, and data collection, followed by data processing and diagnosis of production constraints. The next stage involved developing a production forecast for September–December 2025 and using the forecast results as the basis for mine design and haul-road planning. If the design output was not considered adequate to support production targets, the design stage was revised iteratively until an operationally feasible plan was obtained. Thus, **Figure 3** is not only a generic flow chart, but a representation of the sequential decision-making process used in this study.

The data analysis in this study was conducted in a sequential and integrated manner to ensure that each analytical stage contributed directly to the evaluation of production performance at Pit Rista. The first stage involved comparing the actual coal and overburden production achieved in July and August 2025 with the corresponding production targets in the mine plan. This initial comparison served as the basis for identifying the extent of production

shortfalls and determining whether operational performance during the study period deviated significantly from the planned targets.

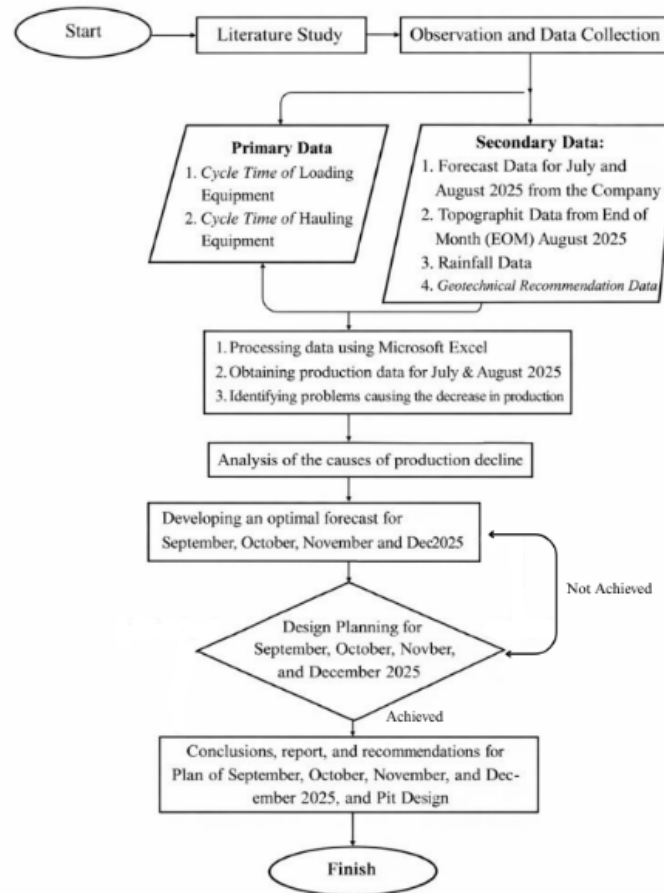


Figure 3. Research Flow Chart

After the overall production performance had been established, the analysis was continued by processing the cycle time data of loading and hauling equipment. The average cycle times obtained from field observations were then used to estimate the productivity of the excavator and dump truck fleet, since cycle time is one of the principal variables influencing the output of loading and hauling operations [15], [16]. The productivity of loading equipment was calculated using Equation (1):

$$Q_L = \frac{K_b \times F_f \times S_f \times E_k \times 3600}{C_{tm}} \tag{1}$$

where Q_L is the productivity of loading equipment (m³/hour), K_b is the bucket capacity (m³), F_f is the fill factor, S_f is the swell factor, E_k is the work efficiency, and C_{tm} is the cycle time of the loading equipment in seconds. In parallel, the productivity of hauling equipment was calculated using Equation (2):

$$Q_H = \frac{N_a \times K_b \times F_f \times S_f \times E_k \times 60}{C_t} \tag{2}$$

where Q_H is the productivity of hauling equipment (m³/hour), N_a is the number of bucket loads per hauling unit, K_b is the bucket capacity (m³), F_f is the fill factor, S_f is the swell factor, E_k is the work efficiency, and C_t is the hauling cycle time in minutes. These two equations were used to quantify the performance of the loading and hauling system and to determine whether

production deficiencies were associated with reduced productivity at the excavation stage, the hauling stage, or both.

To complement the productivity analysis, the study also evaluated the utilization of available operating time through working efficiency, physical availability (PA), and use of availability (UA). Working efficiency was assessed by comparing effective working time with the total available working time during the study period. Subsequently, equipment condition and operational utilization were examined using PA and UA, because these indicators are widely used to distinguish between equipment readiness and the extent to which available equipment is actually used in production [17], [18]. Physical availability was calculated using Equation (3):

$$PA = \frac{WH+SH}{AH} \times 100\% \quad (3)$$

where PA is physical availability (%), WH is worked hours, SH is standby hours, and AH is available hours. Use of availability was calculated using Equation (4):

$$UA = \frac{WH}{WH+SH} \times 100\% \quad (4)$$

where UA is use of availability (%), WH is worked hours, and SH is standby hours. Through these calculations, the study was able to determine whether the observed production shortfalls were related to low equipment availability, low utilization of available units, or a combination of both conditions.

Once the equipment performance indicators had been established, the next stage was to examine the causes of lost working time. Loss-time data were classified into idle time, delayed time, and downtime, and were then ranked using Pareto analysis in order to identify the dominant factors contributing to operational inefficiency. In this study, the Pareto diagram was used as a bar-chart-based prioritization tool supported by cumulative percentage, making it possible to distinguish the relatively small number of factors that contributed most to the decline in effective working hours [19], [20]. This stage was essential because production inefficiencies in open-pit mining are often caused not only by low equipment productivity, but also by the accumulation of operational interruptions that reduce the time available for actual mining activities.

After identifying the main time-related and equipment-related constraints, the analysis was extended to the conformity of mining sequence implementation in the field. This stage was carried out by comparing the planned monthly mining design with actual pit progress at the end of the month, supported by rainbow design evaluation using mining software. The purpose of this comparison was to determine whether production shortfalls were also associated with deviations from the intended mining sequence, including undercut areas, overcut areas, and areas that remained in accordance with the mine plan. In this way, the study did not only evaluate production numerically, but also assessed whether the spatial progression of mining activities remained consistent with the design basis used for operational planning.

Because material transportation is also strongly influenced by haul-road conditions, the analysis further included an evaluation of haul-road geometry. Road width and road gradient were assessed because both parameters directly affect hauling efficiency, cycle time, and operational safety [19]. The minimum straight haul-road width was calculated using Equation (5):

$$L = n \times W_t + (n + 1) \left(\frac{1}{2} W_t \right) \quad (5)$$

where L is the minimum haul-road width (m), n is the number of lanes, and W_t is the width of the largest hauling equipment (m). This calculation was applied to evaluate whether the

existing and planned road geometry was sufficient to support the movement of hauling equipment during the optimized production period.

Finally, the results from the production analysis, equipment productivity calculations, working-time evaluation, loss-time diagnosis, mining sequence conformity assessment, and haul-road geometry analysis were integrated into the preparation of a production forecast for September to December 2025. This forecast was then used as the basis for revising the pit design and haul-road layout so that the proposed operational plan for the following months was grounded in the actual constraints identified during July and August 2025. Through this sequence of analysis, the study was able to move systematically from diagnosing the causes of production underachievement to formulating technically relevant recommendations for production improvement.

Equipment and Software

Data processing and analysis were conducted using Microsoft Excel for production calculations, productivity analysis, work-efficiency evaluation, PA and UA calculations, and Pareto-based diagnosis. In addition, Minescape, Surpac, and ArcGIS were used to support mine design checking, rainbow overlay evaluation, topographic interpretation, and spatial analysis of pit progress. The use of specialized mining and spatial software in combination with spreadsheet-based operational calculations is consistent with recent mine-planning and mine-performance evaluation practice [18], [19].

RESULT AND DISCUSSION

Analysis of Working Hours in July and August 2025

The actual working-hour records for July and August 2025 indicate that the effective working hours were lower than the planned values in both months. As presented in [Table 2](#), the planned effective working hours were 434.40 hours in July and 430.31 hours in August, whereas the actual effective working hours were only 371.90 hours and 302.42 hours, respectively. At the same time, standby working hours increased from 309.60 hours in the July plan to 372.10 hours in the July actual record, and from 301.68 hours in the August plan to 429.57 hours in the August actual record. These data show that working-time losses became more severe in August than in July.

The distribution of loss time also differed between the two months. In July, the main increases were observed in rain, slippery road conditions, refueling, no-hauler delay, and maintenance. In August, the most prominent increases occurred in rain, slippery conditions, waiting weather condition, and maintenance. In particular, waiting weather condition rose to 74.00 hours in August, while maintenance reached 98.40 hours. These values are consistent with the reduction in effective working hours recorded in the same month.

Table 1. Working Hours for July and August 2025

Description	Unit	July Plan	July Actual	August Plan	August Actual
Calendar Days	days	31	31	31	31
Holidays	days	0	0.5	0.5	0.5
Available Day	days	31	30.5	30.5	30.5
MOHH	hours	744	732	732	732
Idle Time					
Rain	hours	18.17	22.9	16.5	68.73
Slippery	hours	10.9	17	9.9	42
Change Shift	hours	62	63.2	61	39.275

Description	Unit	July Plan	July Actual	August Plan	August Actual
Rest Time–Meals	hours	62	66.4	61	34.34
Friday Pray	hours	4	4	5	5
Safety Talk	hours	5	5	4	4.1
Joint Survey & EOM	hours	6	6	5	5
Delayed Time					
Refueling	hours	10.3	16.3	10.2	11.1
Prepare / Travel Time	hours	10.3	10.3	10.2	10.3
Waiting Weather Condition	hours	-	14.5	-	74
No Hauler (No Driver)	hours	-	24.4	-	10.6
Others (ES, BR, AR, EF)	hours	46.5	30.6	30.5	26.35
Down Time					
Maintenance	hours	74.4	91.55	88.45	98.4
Effective Working Hours	hours	434.4	371.9	430.31	302.42
Standby Working Hours	hours	309.6	372.1	301.68	429.57

The dominant contributors to lost time are shown in the Pareto diagrams in Figure 4 and Figure 5. In July, the largest contributor was No Driver/No Hauler, amounting to 24.4 hours or 31% of the total major loss-time components. This was followed by maintenance (17.2 hours), waiting weather condition (14.5 hours), and slippery conditions (6.1 hours). The smallest contributor shown in the July Pareto diagram was change shift, at 1.2 hours or about 1%.

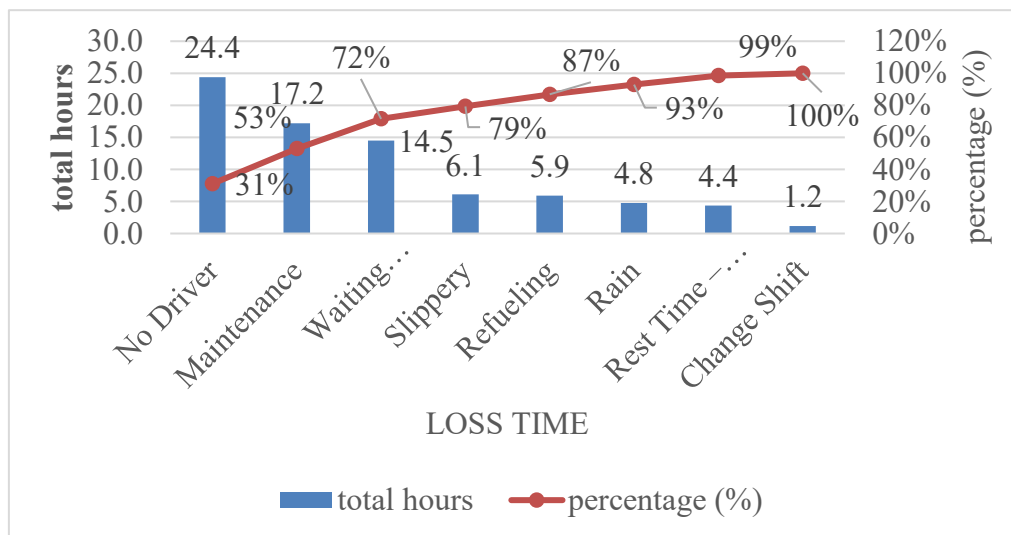


Figure 4. Pareto Loss July 2025

In August, the dominant contributor changed. As shown in Figure 5, waiting weather condition became the largest source of lost time at 74.0 hours, contributing approximately 41% of the total highlighted losses. This was followed by rain (52.2 hours), slippery conditions (32.1 hours), no driver (10.6 hours), and maintenance (10.0 hours). Refueling, prepare/travel time, and safety talk contributed only minor portions of the total loss time. These figures confirm that

the main loss-time source shifted from fleet-related constraints in July to weather-related delays in August.

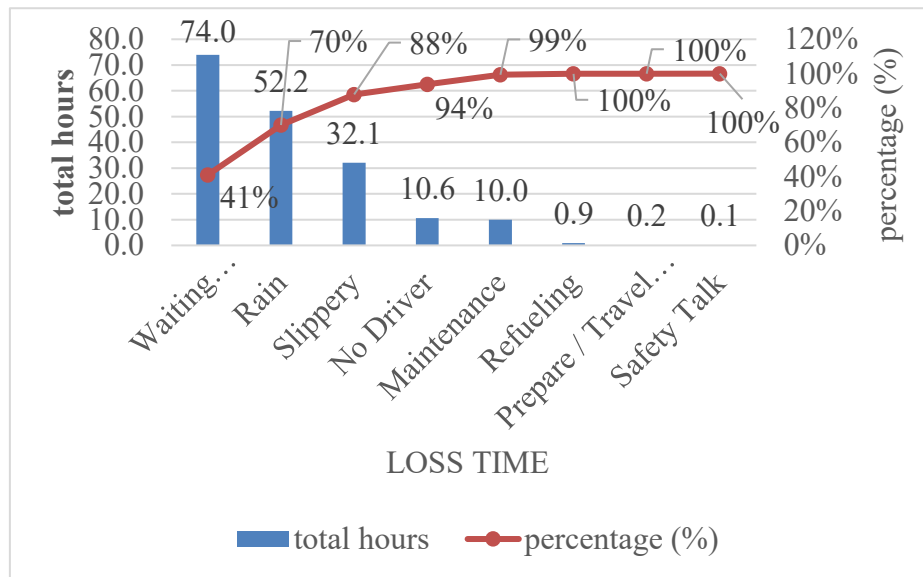


Figure 5. Pareto Loss August 2025

Production Achievement Against the Mining Plan

The productivity of the Hitachi ZX 350 excavator and the associated dump trucks is summarized in Table 3. The loading-equipment productivity increased from July to August for all material types. For clay, excavator productivity rose from 187.42 m³/hour to 198.29 m³/hour. For sand, it increased from 181.66 m³/hour to 198.83 m³/hour. Coal productivity also increased from 239.71 tons to 264.29 tons.

In contrast, hauling productivity declined over the same period. Dump-truck productivity for clay decreased from 49.44 m³/hour in July to 34.75 m³/hour in August, while sand hauling productivity fell from 33.23 m³/hour to 28.02 m³/hour. Coal hauling productivity also decreased slightly from 56.06 tons to 54.90 tons. Thus, although loading productivity improved in August, hauling productivity weakened, indicating a difference in performance between the loading and hauling systems during the study period.

Table 3. Productivity of Excavator and Dump Truck

Month	Material	Excavator Productivity	Dump Truck Productivity	Unit
July	Clay	187.42	49.44	m ³ /hour
July	Sand	181.66	33.23	m ³ /hour
July	Coal	239.71	56.06	ton
August	Clay	198.29	34.75	m ³ /hour
August	Sand	198.83	28.02	m ³ /hour
August	Coal	264.29	54.9	ton

Analysis of Physical Availability (PA) and Use of Availability (UA)

The results of the PA and UA evaluation for excavators, bulldozers, and dump trucks are presented in Table 4. In July, the excavator recorded an actual PA of 86% and UA of 56%, both slightly higher than the planned values of 84% and 50%. The dump truck also showed a slightly higher actual PA (81%) than planned (80%), but its actual UA (50%) was lower than the

planned 56%. The most notable difference occurred in the bulldozer, where the actual PA in July was only 42% compared with the planned 78%, although its actual UA reached 61%, which exceeded the planned 44%.

In August, the excavator maintained a relatively high actual PA (86%) compared with the planned 80%, but its UA declined to 42%, below the planned 48%. The bulldozer showed an actual PA of 70% and UA of 42%, both lower than or close to the planned values. The dump truck recorded an actual PA of 87%, higher than the planned 81%, but its actual UA decreased to 40%, compared with the planned 49%. These results indicate that equipment availability and equipment utilization did not move in the same direction for all equipment types and months.

Table 4. PA and UA Values for July and August 2025

Equipment Type	July Plan PA	July Plan UA	July Actual PA	July Actual UA	August Plan PA	August Plan UA	August Actual PA	August Actual UA
Excavator	84%	50%	86%	56%	80%	48%	86%	42%
Bulldozer	78%	44%	42%	61%	71%	44%	70%	42%
Dump Truck	80%	56%	81%	50%	81%	49%	87%	40%

Based on these values, the July standby condition was mainly associated with dump-truck operation, whereas in August high standby time was recorded across all major equipment types. This is consistent with the loss-time results presented in [Figure 5](#), where weather-related waiting time became the largest source of delay in August.

Mining Progress Based on the Planned Mining Sequence

The planned mining sequence for July 2025 is shown in [Figure 6](#). In this design, the magenta line marks the planned mining boundary, the green line represents the slope crest, the red dashed line shows the planned slope toe, and the cyan dashed-center line represents the haul road intended to support overburden and coal transportation. These elements define the monthly mining sequence to be executed in the field.

The comparison between the planned sequence and the end-of-month mine progress is shown in [Figure 7](#) through the rainbow overlay analysis. The overlay indicates that the July–August design was not fully implemented in the field. The violet areas represent zones where excavation exceeded the planned mining sequence (overcut), while the yellow and red areas indicate zones where excavation was below the planned sequence (undercut). The green and blue areas represent zones that remained in accordance with the design (in plan). This figure shows that actual mine progress varied spatially relative to the planned monthly sequence.

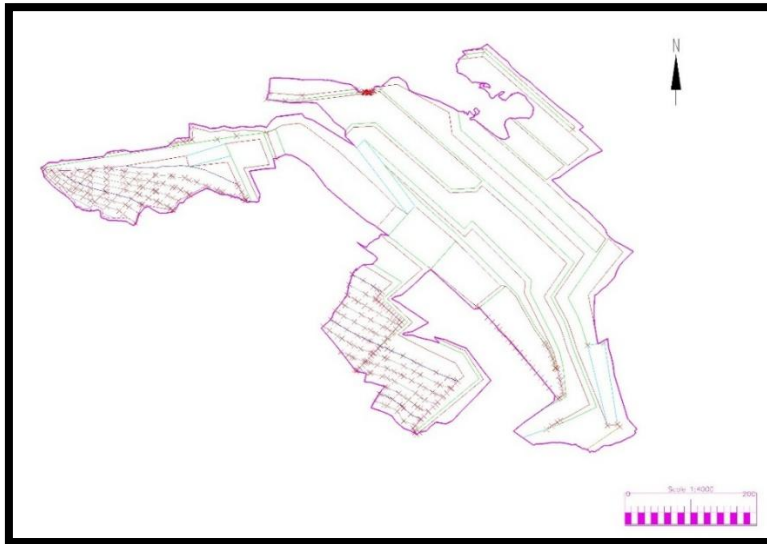


Figure 6. Mining Design for July 2025

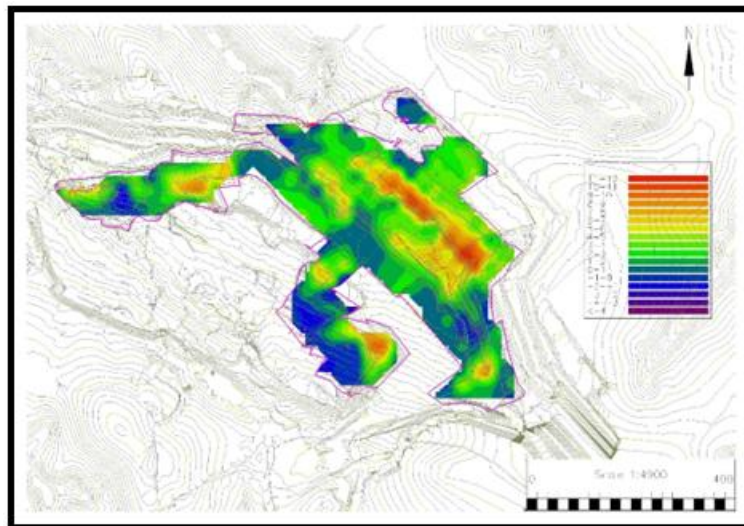


Figure 7. Mine Progress at the End of July 2025

Production Plan for September to December 2025

After evaluating production performance from January to August 2025, the cumulative coal production achievement reached 614,764.76 tons, or 54% of the 2025 target of 1,131,746 tons. This left a remaining requirement of approximately 516,980.79 tons to achieve the annual coal target. Overburden production reached 1,225,921 m³, or 47.9% of the annual target of 2,559,419 m³, leaving a remaining requirement of 1,333,498 m³. Based on these shortfalls, the monthly production plan for September–December 2025 was prepared, as shown in Table 5.

Table 5. Production Plan for September to December 2025

Month	Coal (BB) (ton)	Overburden (OB) (m ³)
September	137,570.07	336,865.32
October	137,216.97	326,864.82
November	126,939.24	317,712.76
December	122,071.15	307,128.39

The planned working hours supporting this production target are summarized in [Table 6](#). Planned effective working hours were 426.10 hours in September, 418.78 hours in October, 376.50 hours in November, and 398.46 hours in December. The corresponding standby working hours were 263.90 hours, 289.06 hours, 313.50 hours, and 257.04 hours, respectively. Rain and slippery conditions remained part of the monthly plan, with the highest rain allocation occurring in November (97.50 hours). Maintenance was planned between 28.50 and 36.17 hours across the four months.

Table 6. Planned Working Hours for September to December 2025

Description	Unit	September	October	November	December
Calendar Days	days	30	31	30	29
Holidays	days	–	–	–	0.5
Available Day	days	30	31	30	28.5
MOHH	hours	720	744	720	684
Idle Time					
Rain	hours	63	65.1	97.5	59.85
Slippery	hours	25.2	26.04	39	23.94
Change Shift	hours	60	62	60	57
Rest Time–Meals	hours	60	62	60	57
Friday Pray	hours	4	5	4	4
Safety Talk	hours	1.2	2.5	2	1.75
Joint Survey & EDM	hours	5.5	7	6	6
Delayed Time					
Refueling	hours	5	5.17	5	4.75
Prepare / Travel Time	hours	5	7.75	5	7.13
Other	hours	5	10.33	5	7.13
Down Time					
Maintenance	hours	30	36.17	30	28.5
Effective Working Hours	hours	426.1	418.78	376.5	398.46
Standby Working Hours	hours	263.9	289.06	313.5	257.04

To support the September–December production plan, target values for equipment availability and utilization were also established, as presented in [Table 7](#). Planned PA ranged from 95% to 96%, while planned UA ranged from 55% to 62% over the four-month period. These target values were set to support the required production achievement for the remainder of 2025.

Table 7. Planned PA and UA for September to December 2025

Description	September	October	November	December
Physical Availability (PA)	96%	95%	96%	96%
Use of Availability (UA)	62%	59%	55%	61%

Haul-Road Plan for September to December 2025

The Howo Tipper Truck 6×4 371 HP, with a width of 2.6 m, was used as the controlling vehicle dimension for road design. Based on the straight-road calculation, the minimum haul-road width was determined to be 9.1 m. This width was then adopted as the design width for the planned haul road in the mining area.

For the curved sections, the design parameters are presented in [Table 8](#). These include a wheel track width of 3.80 m, two lanes, a front overhang component of 0.66 m, a rear overhang component of 0.40 m, the distance between two adjacent trucks of 2.43 m, and the distance from the outer truck side to the road edge of 2.43 m. Using these parameters, the required curve width was calculated as 17.02 m.

Table 8. Measurement Parameters of Road Curve Width

Parameter	Value
Wheel Track Width (U)	3.80 m
Number of Lanes (n)	2
Front Overhang Width (FA) $\times \sin(19^\circ)$	0.66 m
Rear Overhang Width (FB) $\times \sin(13^\circ)$	0.40 m
Distance Between Two Side-by-Side Trucks (C)	2.43 m
Distance from Outer Truck Side to Road Edge (Z)	2.43 m
Curve Width	17.02 m

Design Plan for September 2025

The revised mining design proposed for September 2025 is shown in [Figure 8](#). This design was prepared as part of the operational planning for the next production period and was intended to improve material extraction and hauling effectiveness in response to the production evaluation results from July and August. The design therefore represents the planned spatial basis for the September operation following the observed deviations between design and field progress in the previous months.

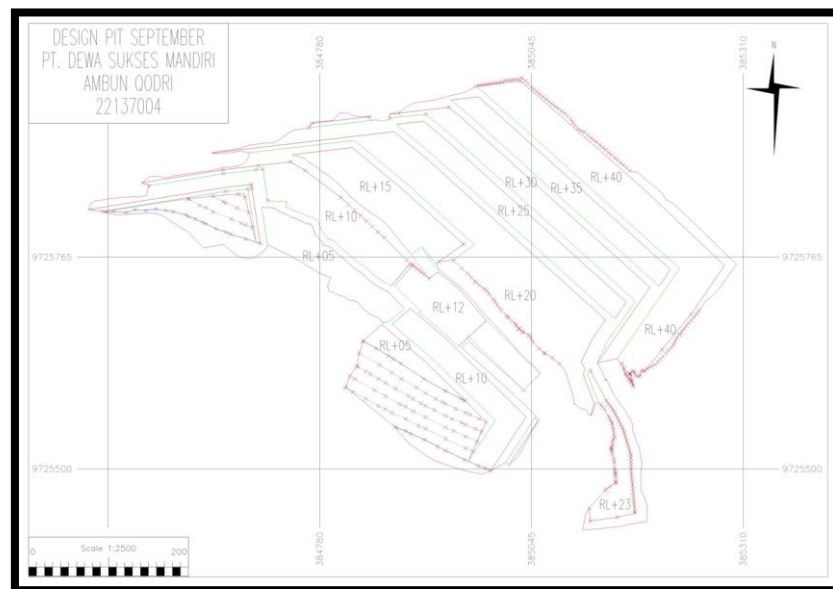


Figure 8. Mining Design for September 2025

Discussion

The results presented in [Table 2](#) show that the principal operational constraint during July and August 2025 was not the nominal monthly working schedule, but the marked reduction in actual effective working hours. In July, effective working hours declined from 434.40 hours in

the plan to 371.90 hours in actual operation, and in August they dropped further from 430.31 hours to 302.42 hours. At the same time, standby working hours increased substantially, reaching 429.57 hours in August. When these values are interpreted together with the Pareto diagrams in [Figure 4](#) and [Figure 5](#), the production shortfall can be understood as the result of two different but equally critical bottlenecks. In July, the most dominant source of lost time was No Driver/No Hauler, which contributed 31% of total loss time, whereas in August the dominant factor shifted to Waiting Weather Condition, which accounted for 41%. This pattern indicates that the reduction in production was closely associated with the loss of productive operating time before the loading–hauling system could operate at its intended capacity. Such findings are consistent with previous studies showing that short-term open-pit production is highly sensitive to working-time losses, mine-to-plan compliance, and haulage continuity, where delays in truck support, queuing, and nonproductive cycle components can significantly reduce output [3], [18], [21], [22]. In this regard, the results suggest that the production problem at Pit Rista was not merely a matter of insufficient equipment capacity, but of how effectively available time was converted into real productive work.

A similar pattern can be observed in [Table 3](#), which shows a contrasting relationship between loading and hauling performance during the study period. Excavator productivity increased from July to August for all material types, while dump-truck productivity declined over the same period. This means that the deterioration in production performance in August was not primarily caused by loading capacity, since the excavator was able to achieve higher productivity values. Instead, the operational bottleneck appears to have shifted toward the hauling system, where lower truck productivity reduced the mine’s ability to translate excavation output into actual material movement. In practical terms, the increase in excavator productivity did not result in higher total production because the hauling fleet could not sustain the same level of performance. This interpretation is in line with truck–shovel performance studies showing that excavation output may remain stable or even improve while total mine output still decreases when haulage cycle time becomes longer, road conditions deteriorate, or dispatch efficiency weakens [15], [16], [22]. Therefore, the present results indicate that the main issue at Pit Rista was not a general decline in equipment productivity, but an imbalance between the excavation stage and the material transport stage of the production system.

Further evidence of this imbalance is provided by the PA and UA values in [Table 4](#), which show that equipment performance cannot be evaluated solely on the basis of availability. The excavator maintained relatively high actual PA values in both months, and the dump truck also showed acceptable actual PA values. However, UA decreased for several units, particularly in August, indicating that available equipment was not fully converted into productive operating time. This distinction is important because high PA does not automatically guarantee high utilization when equipment remains on standby due to weather, waiting time, or limitations in front readiness. Therefore, when [Table 2](#), [Table 4](#), and [Figure 5](#) are interpreted together, the August production decline appears to have been constrained more by operating conditions and standby accumulation than by purely mechanical unavailability. The bulldozer results are particularly notable. In July, its actual PA was only 42%, far below the planned 78%, while UA reached 61%; in August, PA improved to 70%, but UA remained low at 42%. These values suggest that bulldozer support was unstable during the study period, which is operationally significant because bulldozers contribute to front preparation, road maintenance, and work-area readiness. Even so, because the results section does not include unit-level breakdown histories or a detailed maintenance analysis for each equipment category, the exact mechanism should be interpreted cautiously. What can be concluded with confidence is that unstable support equipment performance likely reduced the smoothness of field preparation and indirectly affected hauling continuity. This interpretation is consistent with previous research

showing that availability and utilization are interrelated but distinct indicators, and that meaningful operational improvement is achieved only when equipment readiness, maintenance quality, and actual system use are evaluated together [7], [17], [23].

The spatial dimension of the production problem is further clarified by the comparison between Figure 6 and Figure 7, which shows that the planned mining sequence for July–August 2025 was not fully implemented in the field. The rainbow overlay reveals the coexistence of overcut, undercut, and in-plan zones, indicating that mine progress did not consistently follow the intended monthly design. This is an important result because open-pit production targets are determined not only by the quantity of coal and overburden moved, but also by whether extraction proceeds in the correct spatial order. When actual excavation progresses differently from the planned sequence, the result may be delayed stripping, uneven coal exposure, and inefficient redistribution of equipment across working fronts. This finding is strongly aligned with the mine-to-plan compliance literature, which shows that better spatial conformity between design and field implementation improves production control and reduces the gap between planned and actual mine progress [3], [5], [21]. Consequently, the production shortfall at Pit Rista should not be interpreted solely as a consequence of loss time or equipment availability problems. It should also be understood as a sequence-execution issue, because deviations from the intended cut geometry directly influence where equipment can work, how material is accessed, and how efficiently overburden stripping and coal winning remain balanced over time.

This interpretation becomes even more relevant when considering the recovery strategy for September–December 2025 presented in Table 5, Table 6, and Table 7. After August, the remaining annual coal target was approximately 516,980.79 tons, while the remaining overburden target reached 1,333,498 m³, so the production plan for the following months should be understood as a recovery plan rather than a routine continuation of normal operations. The planned monthly production targets, revised working-hour allocations, and higher PA–UA targets indicate that management expected a significant improvement in operating performance. However, the evidence from Table 2 and Table 4 suggests that simply setting higher PA and UA targets will not be sufficient. These indicators can only improve sustainably if the underlying causes of standby time are addressed, including front readiness, haul-road condition, weather response, and sequence discipline. Recent studies on fleet management, integrated mine-performance indicators, and real-time truck dispatching similarly show that operational improvement in open-pit mining requires coordinated control of scheduling, dispatch, equipment use, and working-time losses rather than dependence on a single productivity measure [18], [23], [24]. In other words, the success of the September–December recovery plan depends not only on revised targets, but on whether the operational constraints diagnosed in July and August are effectively reduced in practice.

The same integrated perspective applies to the haul-road and mine-design results shown in Table 8 and Figure 8. The road-design analysis indicates that the minimum straight haul-road width should be 9.1 m, while the required curve width is 17.02 m. These values are important because truck movement efficiency is highly sensitive to road width, turning space, gradient, and road-surface condition. Under conditions where Figure 5 identifies weather-related waiting as the largest source of delay, haul-road adequacy becomes more than a geometric design issue; it becomes a critical component of production continuity. This interpretation is supported by recent studies showing that mine-road performance deteriorates under excessive rainfall and seasonal moisture changes, especially when road geometry and maintenance are not rigorously controlled [19], [20], [25], [26]. In the Indonesian mining context, haul-road quality is also closely linked to operational safety and supervision, particularly in hauling and dumping activities [27]. Therefore, the revised design proposed for September 2025 in Figure

8 should be interpreted not only as a production-support measure, but also as part of a broader operational control strategy. If implemented consistently, it can improve truck movement, reduce avoidable delays, and support both productivity and field safety.

Taken together, the results of this study have important practical and academic implications. Operationally, the findings indicate that production control in contractor-based open-pit coal mining should integrate at least four closely related dimensions: effective working hours, dominant loss-time sources, equipment availability and utilization, and mining-sequence compliance. Monitoring only one of these variables will not be sufficient, because the July and August results show that different bottlenecks can dominate in different months. A practical implication is that the operation must distinguish clearly between controllable internal delays, such as no-hauler events and unstable support-equipment performance, and external constraints, such as weather-related interruption, then respond to each using different management strategies. For Pit Rista, this implies tighter dispatch coordination and front supervision under July-type conditions, and stronger weather response, drainage readiness, and road maintenance under August-type conditions. Academically, this study contributes by evaluating production shortfall not only through productivity calculations, but through an integrated reading of mining-sequence execution, time losses, PA–UA performance, and mine-progress conformity. While many previous studies discuss these aspects separately, the present study shows how they interact within one operating pit and one production cycle. As such, it offers a practical analytical model for linking short-term mine planning with field execution, particularly in operations where coal exposure and overburden removal must remain balanced under variable equipment and weather conditions.

At the same time, the findings should be interpreted within the limits of the study design. The analysis covers only two months of detailed operational performance, so it reflects short-term variation rather than long-term seasonal behavior. In addition, the evaluation is based on one pit and one contractor operation, which means that direct generalization to other mines should be made cautiously. Although the study makes effective use of PA, UA, cycle time, and sequence conformity, the available dataset does not include detailed unit-level maintenance histories or a separate statistical model linking each delay factor to the magnitude of production loss. For that reason, the discussion supports a strong site-specific operational interpretation, but not a claim of universal causality for all open-pit coal mines. This limitation does not reduce the practical importance of the findings, but it does mean that the conclusions are most reliable as an integrated operational diagnosis and planning basis for Pit Rista itself.

CONCLUSION

The results indicate that the failure to achieve coal and overburden production targets at Pit Rista during July and August 2025 was mainly caused by the combined effect of low effective working hours, high loss time, unstable equipment utilization, and incomplete implementation of the planned mining sequence. Effective working hours declined from 371.90 hours in July to 302.42 hours in August, while standby working hours increased to 429.57 hours in August. The dominant source of loss time shifted from No Driver/No Hauler (31%) in July to Waiting Weather Condition (41%) in August. In addition, excavator productivity increased while dump-truck productivity declined, indicating that the main bottleneck was more closely related to haulage performance than to digging capacity. The PA and UA results also show that equipment availability alone was not sufficient to ensure productive operation, and the overlay analysis confirms that actual mine progress did not fully follow the planned mining sequence. Overall, the production shortfall reflected weak integration between working-time efficiency, fleet performance, and sequence execution.

Accordingly, production improvement should focus on a more integrated operational control strategy. This includes reducing the dominant sources of delay, improving the practical use of available equipment, strengthening supervision of excavator placement and front development so that field progress remains aligned with the mining sequence, and implementing the haul-road and pit-design improvements prepared for the September–December 2025 recovery plan. The revised plan should therefore be treated not only as a new production target, but as an operational control framework that links working-hour management, equipment utilization, mining-sequence compliance, and road readiness. Although the study is limited to one pit and a two-month evaluation period, it provides a practical basis for improving short-term production control at Pit Rista and for guiding future monitoring of production performance under varying operational conditions.

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