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Productivity Assessment of Digging and Loading Equipment (Cat 330D2L) and Hauling Equipment (Fuso 220PS) in Coal Mining at PT. Bhumi Sriwijaya Perdana Coal, Musi Banyuasin Regency, South Sumatra

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Abstract: PT. Bhumi Sriwijaya Perdana Coal, a coal mining company located in Musi Banyuasin District, South Sumatra, utilizes Caterpillar 330D2L excavators and Mitsubishi Fuso 220PS dump trucks for coal extraction activities. The company set a production target of 52,612 tons/month for March 2023. However, actual production fell short, with the hauling equipment achieving only 41,260.08 tons/month, despite the loading equipment exceeding the target with 59,086.93 tons/month. This research aims to identify factors hindering the achievement of production targets and propose strategies for improvement. The analysis revealed that the mismatch between the loader and hauler operations, reflected by a low match factor of 0.57, was a significant contributor to inefficiencies. Additional challenges included extended cycle times influenced by front-loading patterns, hauling path conditions, and equipment synchronization. After implementing improvements, including cycle time optimization and increased loading flow, the productivity of the Mitsubishi Fuso 220PS dump trucks increased to 59,732.67 tons/month. The match factor between the Caterpillar 330D2L and the Mitsubishi Fuso 220PS improved to 0.83, demonstrating enhanced operational alignment. These findings highlight the importance of addressing cycle times, optimizing equipment compatibility, and improving workflows to meet production targets effectively.

Keywords: Coal mining, loading equipment, hauling equipment, match factor, productivity

INTRODUCTION

The mining industry serves as a key driver of economic development in Indonesia, particularly in resource-rich regions such as South Sumatra. Within this context, PT. Bhumi Sriwijaya Perdana Coal operates in Beji Mulyo Village, Tungkal Jaya District, Musi Banyuasin Regency, under an IUP (Mining Business License). The company employs open-pit mining techniques, a widely used method that involves the systematic removal of overburden and coal. This approach relies heavily on the use of advanced mechanical equipment to ensure efficient production and meet the growing demand for coal in both domestic and international markets (Zaky & Anarta, 2022). As such, the performance of heavy machinery plays a critical role in achieving operational success, emphasizing the need for optimization in equipment utilization, minimizing downtime, and maintaining consistent productivity levels (Suryanita & Maiyudi, 2023; Utama et al., 2021).

At PT. Bhumi Sriwijaya Perdana Coal, mining operations are broadly categorized into two main activities: coal extraction and overburden removal. These tasks require precise planning and execution, as even minor inefficiencies can have a cascading effect on production timelines and overall output. The performance of heavy equipment, including excavators and dump trucks, is a pivotal factor in determining operational efficiency. Accurate calculations of equipment capacity, cycle times, and synchronization between machinery components are essential to optimize workflow. For instance, studies have highlighted the importance of loading patterns, match factor analysis, and detailed records of turnaround times in enhancing productivity. These methods ensure that loaders and haulers operate in harmony, reducing idle times and maximizing equipment usage (Lanjaya et al., 2022). Such optimizations are particularly crucial in open-pit mining, where delays can lead to significant cost overruns and production shortfalls.

Currently, the company utilizes Caterpillar 330D2L excavators and Mitsubishi Fuso 220PS dump trucks to carry out its mining operations. The Caterpillar excavators exhibit a productivity rate of 59,086.93 tons per month, demonstrating their efficiency in handling large volumes of coal. However, the Mitsubishi dump trucks, which are a critical component of the hauling process, fall significantly short, achieving only 41,260.08 tons per month. This disparity underscores the challenges faced by the company in meeting its monthly production target of 52,612.00 tons. Achieving this target is essential for the company's financial sustainability and its ability to remain competitive within the highly dynamic and resource-intensive mining industry (Sarmidi et al., 2023).

One of the primary factors contributing to the underperformance of the hauling equipment is inefficiency in cycle times. This inefficiency is influenced by several interconnected variables, including road conditions, front loading processes, and limitations in the match factor between loaders and haulers. Additionally, other challenges such as frequent mechanical breakdowns, adverse weather conditions, and bottlenecks in operational workflows further reduce the equipment's capacity to function optimally. For instance, when the compatibility between loading and hauling equipment is not adequately addressed, prolonged waiting times can occur, leading to productivity losses. Such inefficiencies highlight the importance of a comprehensive approach to identifying and mitigating obstacles that impede production.

To address these challenges, this research evaluates the productivity of the digging, loading, and hauling equipment utilized by PT. Bhumi Sriwijaya Perdana Coal. The study focuses on critical factors such as effective working time, cycle times, and match factors to develop actionable strategies for performance improvement. By enhancing equipment compatibility and reducing operational delays, the company can achieve higher levels of efficiency and meet its production objectives. Furthermore, this research contributes to the broader field of mining operations by offering insights into the practical challenges faced in coal mining and proposing solutions that can be adapted to similar contexts within the industry. Ultimately, the findings aim to provide a framework for optimizing mining practices, fostering increased productivity, and ensuring sustainable operations in a competitive environment.

METHOD

This study employs quantitative methods with actual field data collection to identify the causes of not meeting productivity targets. The scope is limited to examining only the Cat 330D2L and Fuso 220PS loading and unloading equipment, without considering economic factors. The stages of this research include a literature review, field observations, primary and secondary data collection, data analysis, and concluding with recommendations. Primary data consists of information collected directly from the field, which has not been previously published. This data includes the loading and transportation patterns of materials, tool cycle times, bulk filling quantities, and field documentation. Secondary data, on the other hand, refers to pre-existing, published data obtained indirectly. This includes basic map data such as geology and research locations, production targets, bottleneck times, mechanical equipment specifications, rainfall data, density, swell factor, and fill factor.

Data processing is conducted using Mechanical Earthmoving formulas, which are applied to various aspects of fleet production. This involves the effective use of mechanical equipment through the match factor method. The results of data processing serve as the basis for evaluating work efficiency, productivity, tool cycle times, tool production per hour, and tool synchronization. Data analysis is carried out using a comparative method by correlating and comparing the research findings with actual analysis results. Additionally, the correlation and comparison between the study results, actual outcomes, and theoretical or planned analyses are thoroughly examined to provide comprehensive insights.

Data processing involves calculations after all the data is collected. To begin, it is necessary to determine the time it takes for the equipment to load, haul, and dig. Cycle time refers to the duration required for heavy equipment to complete one work cycle. The cycle time for the digging tool during loading is calculated using Equation (1) (Hidayat et al., 2019):

$$CTm = Am + Bm + Cm + Dm \tag{1}$$

where CTm = Total cycle time of the loaded device (seconds); Am = Load excavation time (seconds); Bm = Loaded swivel time (seconds); Cm = Charge leakage time (seconds); Dm = Empty swing time (seconds).

The cycle time of a hauling vehicle typically consists of several stages: positioning the vehicle for loading, disposing of cargo, loading cargo, returning to an empty condition, and hauling cargo. The cycle time of the hauler units is calculated using Equation (2) (Hidayat et al., 2019):

$$CTm = Aa + Ba + Ca + Da + Ea + Fa \quad (2)$$

where CTm = Total hauling vehicle cycle time (seconds); Aa = Positioning time for loading (seconds); Ba = Load charging time (seconds); Ca = Carrying load time (seconds); Da = Positioning time for disposal (seconds); Ea = Load disposal time (seconds); Fa = Return time (empty) (seconds).

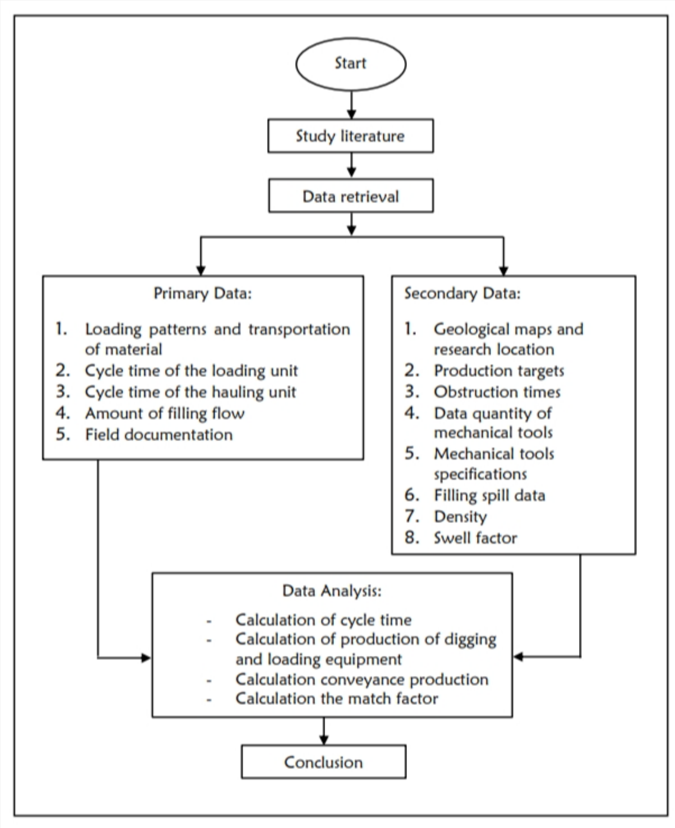

Figure 1. Research Flow Diagram

Work efficiency is defined as the ratio of working hours (efficient time) to the total available working hours. The production capability of equipment is influenced by this efficiency (Oemiati et al., 2020). Work efficiency and effective working time are determined using Equations (3) and (4) (Prodjosumarton, 1980):

$$We = Wt - (Whd + Wtd) \quad (3)$$

$$Ek = \left(\frac{We}{Wt}\right) \times 100\% \quad (4)$$

where We = Effective working time (minutes); Wt = Available work time (minutes); Whd = Time lost due to obstacles (minutes); Ek = Work efficiency (%).

The fill factor, expressed as a percentage (%), represents the ratio of the actual capacity to the capacity of the equipment's bucket. It is calculated using Equation (5) (Pfleider, 1972):

$$Ff = \frac{Vn}{Vb} \times 100\% \quad (5)$$

where Ff = Fill factor (%); Vn = Actual volume of the bucket (m^3); Vb = Theoretical default volume (m^3).

It is also important to assess the physical and mechanical conditions of the equipment to ensure productivity. The efficiency or availability of a device is determined by calculating the Mechanical Availability (MA) using Equation (6) (Indonesianto, 2015):

$$MA(\%) = \frac{w}{w+r} x\ 100\% \tag{6}$$

Physical Availability (PA) accounts for the total time a device is operational during a scheduled working day and is calculated using Equation (7):

$$PA(\%) = \frac{w+s}{T}\ x\ 100\% \tag{7}$$

Use Availability (UA) measures the proportion of time a device is in use relative to its total available time. It is calculated using Equation (8):

$$UA(\%) = \frac{w}{w+s}\ x\ 100\% \tag{8}$$

Effective Utilization (EU) indicates the percentage of total working time used for productive tasks. It is calculated using Equation (9):

$$EU(\%) = \frac{w}{T}\ x\ 100\% \tag{9}$$

where W = Operating hours; R = Repair hours, including maintenance and delays; S = Standby hours, when the equipment is available but not in use; T = Total hours, including working, repair, and standby time (T = W + R + S).

After determining work efficiency and equipment availability, device productivity is calculated. The productivity of digging and loading equipment is determined using Equation (10) (Indonesianto, 2015):

$$PM = \left(\frac{3600}{CTm}\right) x\ Kb\ x\ Ff\ x\ Sf\ x\ Ef\ x\ pi \tag{10}$$

where PM = Productivity of the loaded unit (tons/hour); CTm = Cycle time of the loading unit (seconds); Kb = Bucket capacity (m^3); Ff = Fill factor (%); Sf = Swell factor (%); Ek = Work efficiency (%); Pi = Density (ton/bcm).

The productivity of hauling vehicles is calculated using Equation (11):

$$Pa = \left(\frac{60}{CTa}\right)\ x\ Kb\ x\ Ff\ x\ Ek\ x\ n\ x\ Sfxpi \tag{11}$$

where Pa = Productivity of the hauling unit (tons/hour); Cta = Cycle time of the truck unit (seconds); Kb = Bucket capacity (m^3); Ff = Fill factor (%); Ek = Equipment work efficiency (%); n = Volume of loading flow for the bucket to fill the carrier tank; Sf = Swell factor (%); Pi = Density (ton/bcm).

The required number of tools is calculated using the following formula:

$$\text{The number of toold needed} = \frac{\text{Loader productivity}}{\text{Hauler productivity}} \tag{12}$$

To ensure compatibility between loaders and haulers, the match factor is calculated using Equation (13) (Indonesianto, 2015):

$$Mf = \left(\frac{Na\ x\ n\ x\ CTm}{Nm\ x\ CTa}\right) \tag{13}$$

where Na = Number of hauling equipment; Nm = Number of loading equipment; CTm = Cycle time of the loader; Cta = Cycle time of the hauler; n = Volume of bucket flow.

Based on the match factor results, there are three possible scenarios:

1. If MF < 1, the loader operates below capacity, while the hauler operates at full capacity, causing delays.
2. If MF = 1, both the loader and hauler operate at full capacity without delays.
3. If MF > 1, the loader operates at full capacity, while the hauler operates below capacity, causing idle time.

RESULT AND DISCUSSION

Production Performance of Mining Equipment

In March 2023, the production target for PT. Bhumi Sriwijaya Perdana Coal was set at 52,612.00 tons per month. However, the actual performance of the equipment fell short of this goal, with the hauling equipment achieving only 41,260.08 tons per month, while the loading equipment, specifically the Caterpillar 330D2L excavator, achieved 59,086.93 tons per month. This discrepancy indicates that hauling capacity is the primary bottleneck preventing the overall system from meeting its production targets. Figure 2 illustrates the loading pattern employed at the site, emphasizing a top-loading method and a single back-up pattern, where haulers take turns positioning themselves for loading. Although efficient under certain conditions, this sequential process results in downtime when loaders must wait for haulers to return.

Figure 2. Loading pattern at PT. Bhumi Sriwijaya Perdana Coal.

Operational Characteristics of Loading and Hauling Equipment
Fill Factor and Swell Factor

The fill factor, defined as the ratio of the actual bucket capacity to its theoretical capacity, was measured at 100% for the Caterpillar 330D2L excavator (Figure 3). This demonstrates that the loading equipment is operating at its full design capacity. However, material-specific characteristics such as the swell factor, which quantifies the volume expansion of coal after excavation, also play a crucial role in determining hauling efficiency. The swell factor for the sub-bituminous to bituminous coal in this operation was calculated as 0.74, reflecting a significant increase in volume post-excavation. This factor directly affects the number of hauler loads required to transport a given volume of coal efficiently (Setiawan, 2021).

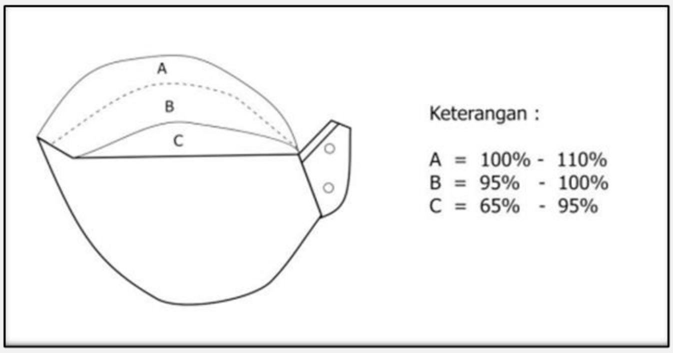

Figure 3. Percent Bucket Fill of Loading Equipment.

Barriers to Achieving Production Targets

A significant factor limiting production is the effective working time of the equipment, which is influenced by both avoidable and unavoidable obstacles. Avoidable obstacles include delays caused by technical and operational inefficiencies, while unavoidable obstacles, such as weather disruptions, represent long-term constraints (Dzulfikar et al., 2023; Akbar et al., 2019). Table 1 compares working hours before and after repairs, highlighting the reduction of avoidable obstacles from 106.56 hours to zero after interventions. This improvement increased work efficiency from 53.38% to 70.00%, demonstrating the impact of optimizing effective working time.

Table 1. Comparison Of Working Hours Before and After Repair

Available Hours	Effective Working Hours Description		Before Repair	After Repair
	Number	Unit		
Calender Days	31	Day	615 Hours	615 Hours
Total Productive Time	31	Day	615 Hours	615 Hours
Unavoidable Obstacles			180,1 Hours	180,1 Hours
Avoidable Obstacles			106,56 Hours	-
Total Barrier			286,66 Hours	180,1 Hours
Work Efficiency			53,38%	70,00%

Cycle Time Analysis

The cycle time of both the loading and hauling equipment plays a pivotal role in determining production capacity. Using Equation 1, the actual cycle time for the Caterpillar 330D2L excavator was calculated as 23.15 seconds (Table 2). This includes digging, swinging, and dumping operations.

Table 2. Average Cycle Time Actual Slider Load

Time	Cycle Time				
	Digging	Swing Loading	Load Time	Swing Empty	Total
Seconds time	9,8	4,5	4,68	4,18	23,15
Minute time	0,16	0,07	0,07	0,06	0,35

For the Mitsubishi Fuso 220PS dump trucks, the initial cycle time, calculated using Equation 2, was 13.15 minutes. This figure encompasses various stages, including waiting for loading, maneuvering, hauling, and dumping (Table 3).

Table 3. Average Cycle Time Actual Vehicle Dump Truck Fuso 220PS

Time	Waiting Time for Loading	Manuver Loading	Loading	Hauling	Manuver Dumping	Dumping	Empty Hauling	Total
Second Time	20,33	46,88	92,53	290,37	55,23	35,72	284,11	789,17
Minute Time	0,33	0,78	1,54	4,83	0,92	0,59	4,13	13,15

After implementing repairs and optimization strategies, the cycle time for the dump trucks decreased to 10.9 minutes, as detailed in Table 4. Figure 4 visually compares the cycle times before and after repair, illustrating the improvement.

Table 4. Average Cycle Time of The Vehicle *Dump Truck* Fuso 220PS After Repair

Time	Waiting Time for Loading	Manuver Loading	Loading	Hauling	Manuver Dumping	Dumping	Empty Hauling	Total
Second Time	3,91	23,68	77,89	265,83	48,45	30,24	204,63	654,62
Minute Time	0,06	0,3	1,2	4,4	0,8	0,5	3,4	10,9

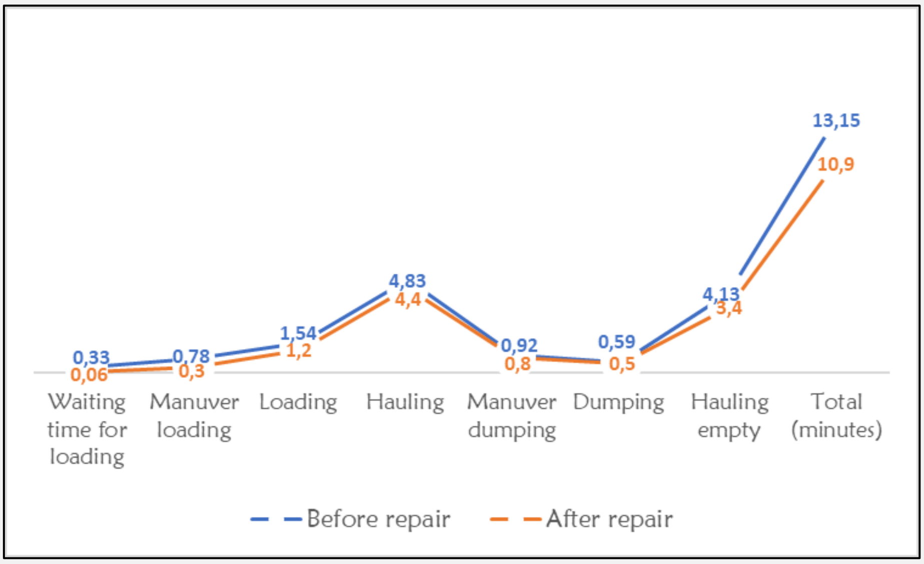

Figure 4. Graph Comparison Cycle Time Carrying Equipment Before and After Repair.

Productivity Analysis

The Caterpillar 330D2L excavator demonstrated an actual productivity of 59,086.93 tons per month, meeting its target. This performance underscores the excavator's operational efficiency, with its cycle time and bucket fill factor both optimized to ensure maximum throughput.

The initial productivity of the Mitsubishi Fuso 220PS dump trucks was 41,260.08 tons per month, falling significantly short of the production target. However, after repairs, including cycle time reductions and increased work efficiency, the productivity rose to 59,732.67 tons per month, as shown in Table 5. Figure 5 compares the productivity levels before and after repairs, emphasizing the substantial gains achieved through these interventions.

Table 5. Comparison of Actual and After Repair Dump Truck Fuso 220PS

Description	Productivity
Productivity Actual Dump Truck Fuso 220PS	41.260,08 Tons/month
Productivity Dump Truck Fuso 220PS After Repair	59.732,67 Tons/month

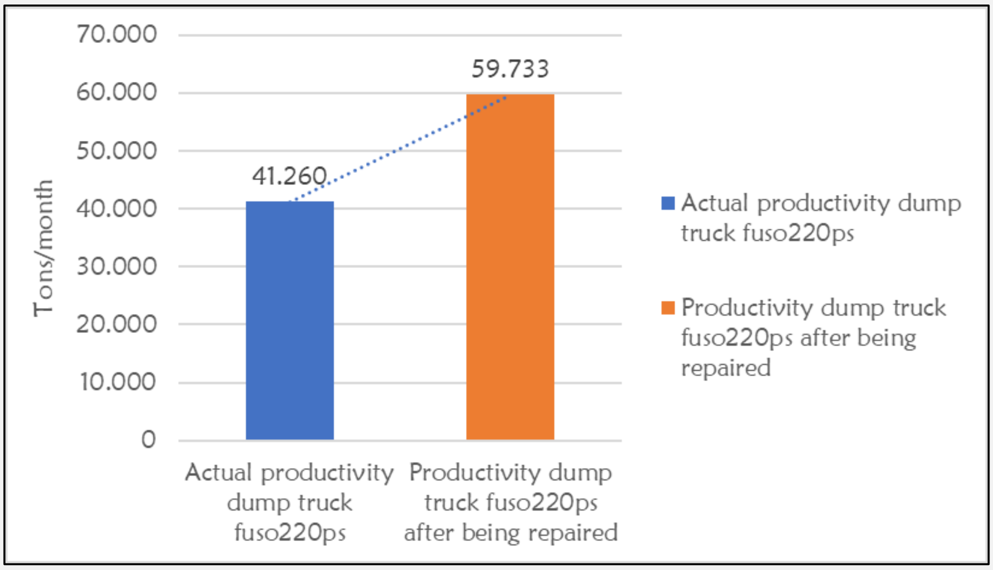

Figure 5. Comparison Productivity Dump Truck Fuso 220PS Actual and After Repairs.

Match Factor Analysis

The match factor, which measures synchronization between loaders and haulers, was calculated using Equation 13. The initial match factor between the Caterpillar 330D2L excavator and the Mitsubishi Fuso 220PS dump trucks was 0.57, indicating inefficiency due to the excavator waiting for haulers to return (Figure 2).

To improve synchronization, adjustments were made, including reducing the cycle time of the dump trucks and increasing the bulk fill per haul from five to six bucket loads. These changes increased the match factor to 0.83, moving closer to the ideal value of 1. While this indicates better alignment, some waiting time for the excavator persists.

The results demonstrate that improving effective working time, reducing cycle times, and optimizing the synchronization between loaders and haulers significantly enhance productivity. The increase in the dump truck productivity by 45%, as shown in Figure 5, underscores the value of these interventions.

However, challenges remain, particularly in achieving a perfect match factor. While the revised match factor of 0.83 represents progress, further adjustments, such as adding additional dump trucks or modifying road conditions, may be necessary to eliminate remaining inefficiencies. Additionally, the reliance on a sequential loading pattern (Figure 2) suggests opportunities for exploring alternative patterns, such as dual or parallel loading configurations, to minimize loader downtime.

The insights gained from this study provide a robust framework for addressing productivity challenges in mining operations, with potential applications in similar industrial contexts. Future research could explore integrating economic factors, evaluating alternative equipment configurations, and employing advanced scheduling algorithms to further enhance operational performance.

DISCUSSION

The production shortfall caused by a low match factor (MF) of 0.57 underscores the importance of equipment synchronization. This inefficiency, where loaders wait for haulers to return, is consistent with findings by Chaowasakoo et al. (2017), who emphasized that low match factors lead to significant production losses and proposed optimizing fleet compositions to balance truck-to-loader ratios. Similarly, Burt & Caccetta (2007) highlighted that equipment under-synchronization often results in underutilized capital-intensive machinery, further affirming the relevance of match factor optimization in mining operations. The observed improvement in the match factor to 0.83, achieved through increased loading flow and reduced cycle time, highlights the efficacy of targeted interventions. This improvement aligns with the recommendations of Hidayat et al. (2019), who reported that achieving a match factor close to 1 minimizes idle time and enhances operational balance.

Cycle time improvements play a pivotal role in addressing productivity gaps. The reduction in cycle time for Mitsubishi Fuso 220PS dump trucks from 13.15 minutes to 10.9 minutes significantly increased productivity, echoing findings by Özdemir & Kumral (2019), who demonstrated that cycle time optimization through simulation led to a 9.4% productivity increase in surface mining. Similarly, Nday & Thomas (2019) emphasized that systematic analysis of cycle time components, such as queuing, loading, and hauling, can reveal significant constraints and opportunities for improvement. The increase in hauling productivity from 41,260.08 tons/month to 59,732.67 tons/month in this study underscores the effectiveness of such measures.

The improvement in work efficiency from 53.38% to 70.00%, achieved by eliminating avoidable obstacles, highlights the significance of addressing operational delays. Mohammadi & Rai (2015) similarly reported that reducing idle times and inefficiencies could markedly enhance equipment productivity, underscoring the importance of optimizing effective working hours. Furthermore, Sembakutti et al. (2017) identified operational uncertainties, such as truck waiting times and breakdowns, as critical barriers to achieving efficient fleet operations.

The 100% fill factor of the Caterpillar 330D2L excavator observed in this study aligns with findings by Adiansyah et al. (2018), who identified fill factors as key determinants of material handling efficiency. Additionally, the recommendation to increase loading flow per haul from five to six buckets improved compatibility, which is consistent with strategies suggested by Hidayat et al. (2019). These findings emphasize the importance of leveraging material-specific characteristics, such as swell factor and fill factor, to enhance equipment synchronization.

The results of this study reinforce the importance of cycle time optimization, work efficiency improvements, and match factor adjustments in addressing productivity challenges in mining operations. The alignment of these findings with existing research demonstrates the broader applicability of these strategies to improve equipment performance and achieve operational targets.

CONCLUSION & RECOMMENDATIONS

The production target for PT. Bhumi Sriwijaya Perdana Coal in March 2023 was set at 52,612.00 tons/month, but the actual performance of the equipment revealed inefficiencies, particularly in the hauling process. While the Caterpillar 330D2L excavator exceeded expectations with a productivity of 59,086.93 tons/month, the Mitsubishi Fuso 220PS dump trucks underperformed, achieving only 41,260.08 tons/month. This gap highlighted the hauling equipment as the primary bottleneck in achieving the production target. Following improvements in cycle time and work efficiency, the hauling equipment's productivity increased to 59,732.67 tons/month, surpassing the target. The key factors contributing to the initial shortfall included inefficiencies in cycle time, affected by road conditions, loading patterns, and the mismatch in equipment synchronization. Initial evaluations revealed a match factor (MF) of 0.57, indicating significant waiting time for the excavator. After implementing recommendations such as increasing the charging flow and optimizing cycle times, the match factor improved to 0.83, reflecting better alignment between the excavator and dump trucks.

Based on these findings, several recommendations are proposed to sustain and enhance operational performance. First, it is essential to strengthen supervision of working hours through direct oversight by foremen or supervisors. This would help identify and minimize obstacles in real-time, ensuring adherence to the optimized work schedule. Second, increasing the bulk filling capacity of coal material into the dump trucks is recommended to further improve equipment compatibility and minimize idle time, thereby enhancing overall productivity. Lastly, implementing a scheduled maintenance program for mechanical equipment is crucial for reducing breakdowns and ensuring consistent performance. Routine maintenance will help the equipment operate at peak efficiency, reducing delays and supporting the company's ability to meet or exceed its production targets. These measures, if implemented effectively, will not only sustain the gains achieved but also position PT. Bhumi Sriwijaya Perdana Coal for long-term success in its mining operations.

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