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Rainfall Duration's Impact on Mining Earthmoving Equipment Performance – Case Study at PT. BUMA GEO-AJE, South Kalimantan

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Abstract This study investigates the impact of rainfall duration on the performance of earthmoving equipment at PT BUMA, GEO-AJE, South Kalimantan. Data from April 2023 covering 29 days were analyzed using SPSS 22 and Origin 2024. The study revealed a 7.06637% decrease in excavator and dump truck efficiency per hour of rainfall. Cycle times were increased by 0.15122 minutes for excavators and 4.50034 minutes for dump trucks per hour of rain. Moreover, excavator productivity declined by 1138.82900 bcm/day and dump truck productivity by 176.21836 bcm/day. These results highlight the necessity of accounting for rainfall in mining operations, especially in productivity forecasts and equipment management.

Keywords: Heavy Equipment; Rainfall Duration; Efficiency; Cycle Time; Productivity; Mining Industry

INTRODUCTION

As early as 2023, the Meteorology, Climatology and Geophysics Agency (BMKG) predicted using various predictive models that some parts of Indonesia will experience extreme weather conditions, including heavy rain, strong winds, and high ocean waves [1], [2], [3]. In the construction industry, weather is a primary focus as it has a significant effect on the productivity of heavy equipment [4], [5], [6]. This is also true in coal mining, where heavy equipment is vital. Some of the standard heavy equipment used in mining projects include dump trucks, compactors, dozers, and excavators [7], [8], [9]. Excavators and dump trucks are the two most commonly used heavy equipment in coal mining [10], [11].

The impact of extreme weather on heavy equipment is significant, especially in the industry [12]. Heavy rain and intense sun exposure can damage the heavy equipment's protective paintwork, increasing the risk of corrosion and damage [13]. Muddy field work caused by rain can cause soil to stick to heavy equipment wheels and components, affecting their performance and lifespan [14]. Proper protection and storage from sunlight and rain are necessary to prevent further damage to heavy equipment, emphasizing the importance of considering extreme weather in equipment maintenance and storage [15], [16]. Additionally, weather-related delays and reduced equipment performance directly impact project timelines and operational costs, making this a crucial consideration for project planning.

Dump trucks and excavators are critical equipment in construction and coal mining projects, each with a unique role. Excavators are used for tasks such as digging, leveling, and transporting loads in construction, while dump trucks assist in transporting materials [17]. The main concern in the coal mining sector is removing overburden to access coal deposits. Therefore, large-scale dump trucks and excavators are required to extract and transport coal to processing facilities [18]. Coal has been the leading mining commodity in Indonesia in recent years. Coal production in 2021 reached 614,058,577 tons, surpassing the production of bauxite, nickel ore, gold, and other commodities [19]. PT Bukit Makmur Mandiri Utama (BUMA) is part of PT Delta Dunia Makmur, one of the leading contractors in the Indonesian coal industry [20]. BUMA has repeat clients, including PT Tanah Bumbu Resources (TBR) in Karang Indah, Angsana, Tanah Bumbu Regency, and South Kalimantan, as part of BUMA's GEO-AJE project [21].

In open-pit coal mining, traditional design methods are generally followed [22], [23], [24]. This process involves mechanized removal of overburden layers by standards set by the project owner, including requirements regarding quality and quantity [25], [26], [27]. Surface mining is commonly used in the exploitation of metal and non-metal ores such as coal [28], [29], [30], [31]. Therefore, planning and setting production targets are essential to ensure the fulfillment of the project owner's demands in terms of quality and quantity.

During the earthmoving stage of mining operations, the characteristics of the overburden can be affected by weather conditions, which can affect the mining process [32]. Rainfall can cause the soil to become soft and more slippery, complicating coal transportation and extraction activities [33], [34], [35]. In addition, it is essential to consider the impact of rainwater temperature on soil erosion, as higher temperatures can affect the rate and mechanism of soil disintegration [36]. Understanding the seasonal changes in soil structure due to rainfall and temperature is essential to predict soil behavior and ensure efficient mining operations, especially during the rainy season, when soil conditions are challenging [37].

Mechanized earthmoving processes are essential in various infrastructure projects, including highway construction, dams, and mining [38], [39]. Measuring heavy equipment efficiency is crucial to ensure optimal performance. Heavy equipment selection and utilization must be carefully considered to operate effectively. Optimal conditions are desired to complete the project at minimal cost and within the target time [40], [41].

Since no previous research considers the effect of rain duration on heavy equipment performance, it is necessary to investigate how it affects excavators and dump trucks in the Main TBR Pit of PT BUMA job site GEO-AJE. This research aims to understand how rain duration affects the productivity of both equipment. Therefore, this research is essential to fill the knowledge gap in this field, offering valuable insights into the relationship between weather and mining productivity, which could be used to improve equipment planning and operational strategies during extreme weather conditions.

METHODOLOGY

Various primary and secondary data were required to analyze the impact of rainfall on heavy equipment, using different data collection processes. The variables utilized in this study were efficiency (E), average cycle time ($\overline{Ct}$), and daily productivity (QAH) of excavators and dump trucks as dependent variables, while the duration of rainfall (t) Served as the independent variable. The indicators used are the effect of rainfall duration (t) on, efficiency (E), average cycle time ($\overline{Ct}$), and daily productivity (QAH) Of excavators and dump trucks. Data analysis employed statistical analysis, primarily through descriptive statistics and linear regression, which proved to be a robust approach to analyzing the data [42], [43]. Descriptive statistics summarized the main characteristics of the data, such as mean, median, and variability, while linear regression allowed for exploring the relationships between variables and predicting responses [44]. This approach enhanced data interpretation and yielded valuable insights for various fields of study. The analysis in this research was conducted using SPSS 22 and Origin 2024 software.

Research Location

The research was conducted on the mechanical soil removal process for the overburden layer in the North TBR Pit of the PT. BUMA GEO-AJE job site is located in Karang Indah, Angsana, Tanah Bumbu Regency, South Kalimantan (72275), as depicted in Figure 1.

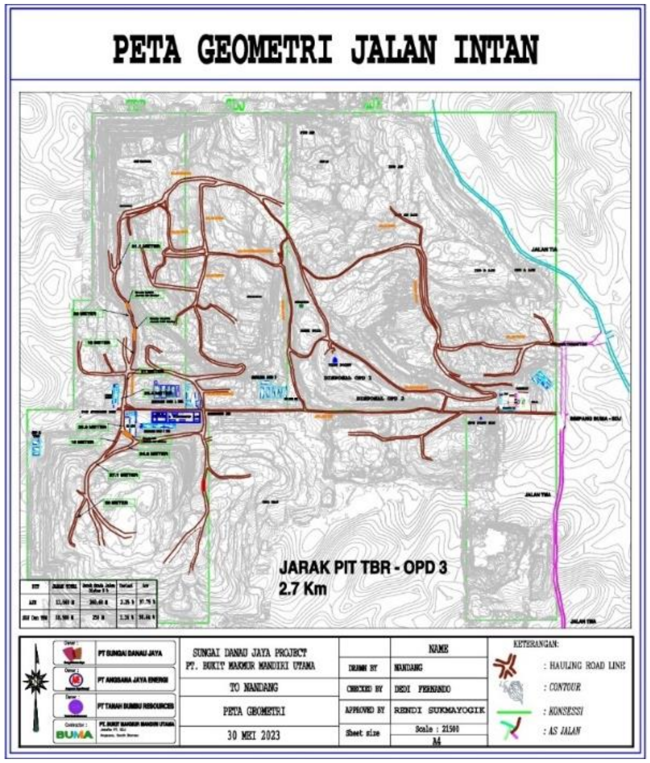


FIGURE 1. Research location

Data Collection

Data collection for this study took place over 29 days, from April 01, 2023, to April 30, 2023. The research gathered data from two primary sources using various data collection methods. Firstly, primary data was obtained through field observations and interviews. Field observations involved direct monitoring of the cycle times (Ct) of excavators and dump trucks in the front loading area, as well as documenting excavator filling (BF) And loading patterns via CCTV dispatch. Additionally, interviews were conducted with mentors to confirm various aspects related to heavy equipment and the rainfall duration (t) Data collection process.

Secondly, secondary data was acquired through literature reviews and the company's internal data archives. Literature reviews were used to obtain technical specifications of excavators and dump trucks. Meanwhile, the company's internal data archives provided information on the number of heavy equipment populations, slippery times (WS), and rainfall duration (t) Data. Through the combination of these data collection methods, this research was able to generate a comprehensive dataset for further analysis.

Number of Samples

Determining the sample size in a study plays a crucial role in ensuring the statistical validity of the research findings. There are various approaches to calculating an appropriate sample size, one of which is using the Slovin formula [45]. Careful sample size calculation is vital to avoid the risk of a sample that is too small to detect significant effects or, conversely, a sample that is too large, which could result in a waste of resources [46]. The population sample used in this study was determined using the Slovin formula with the desired sampling error of 5% based on the total population of Komatsu PC2000-8 and Komatsu HD785-7 dump trucks operating in the North TBR Pit with the OPD 3 discharge direction. Equation (1) can be used to determine the sample size.

$$n = \frac{N}{1+(N \times e^2)} \tag{1}$$

where nIs the sample size, NIs the population, and eIs the percentage of allowance for sampling error still desired?

Cycle Time of Heavy Equipment

Heavy equipment cycle duration, a crucial aspect of excavator and dump truck operations, reflects the time required to complete a production run, especially applicable to heavy equipment that does not operate continuously [47]. Several factors affect this cycle time, such as the site's topographic conditions, the equipment's technical specifications, and optimization efforts such as road repair and surfacing [48]. Equation (2) and Equation (3) can be used to determine the cycle time.

$$Ct_{excavator} = tm + tpb + tb + tpk \tag{2}$$

where $Ct_{excavator}$ (min) is the excavator cycle time, tm (min) is the excavation time, tpb (min) is the turn time with load, tb (min) is the load dump time and tpk (min) is the turn time without load.

$$Ct_{dump\ truck} = tm + tam + tk + tb + tt \tag{3}$$

where $Ct_{dump\ truck}$ (min) is the cycle time of the dump truck, tm (min) is the load time, tam (min) is the load transport time, tk (min) is the empty return time, tb (min) is the load dump time and tt (min) is the load waiting time.

Gross Productivity of Heavy Equipment

The gross productivity formula for excavators and dump trucks can be determined by calculating the amount of material moved per unit of time without considering the efficiency of the heavy equipment in moving the material [49]. Equation (4) and Equation (5) can be used to determine gross productivity.

$$Q_{excavator} = \frac{KP \times BF \times 60}{tm_{dump\ truck}/4} \tag{4}$$

where $Q_{excavator}$ (bcm/hour) is the excavator's gross productivity per hour, KP (bcm) is the bucket capacity of the excavator, BF (%) is the bucket factor of the excavator bucket, and $tm_{dump\ truck}$ (min) is the loading time of the dump truck.

$$Q_{dump\ truck} = \frac{C \times 60}{Ct_{dump\ truck}} \tag{5}$$

where $Q_{dump\ truck}$ (bcm/hour) is the gross productivity of the dump truck per hour, C (bcm) is the vessel capacity of the dump truck, and $Ct_{dump\ truck}$ (min) is the cycle time of the dump truck.

Effective Time

The effective time formula for heavy equipment can be determined by calculating the amount of time available (WP) minus the obstacle time (WH). Equation (6) can be used to determine the adequate time.

$$WE = WP - (t + WS) \tag{6}$$

where WE (hour) is the adequate time for the heavy equipment per day, WP (hour) is the available heavy equipment time per day, t (hour) is the rain duration drag time per day, and WS (hour) is the rain-induced slippery drag time per day.

Efficiency

The efficiency formula for heavy equipment can be determined by calculating the percentage of adequate time (WE) divided by available time (WP). Equation (7) can be used to determine efficiency.

$$E = \frac{WE}{WP} \times 100\% \tag{7}$$

where E (%) is the percentage efficiency of the heavy equipment, WE (hour) is there adequate time for the heavy equipment per day, and WP (hour) is the available heavy equipment time per day.

Actual Productivity of Heavy Equipment

The actual productivity formula for excavators and dump trucks can be determined by calculating the sum of gross productivity (Q) multiplied by the efficiency (E) Of each heavy equipment [50]. Equation (8) can be used to determine the actual productivity.

$$QA = Q \times E \tag{8}$$

where QA (bcm/hour) is the actual productivity per equipment hour, Q (bcm/hour) is the gross productivity per equipment hour, and E (%) is the percentage of equipment efficiency in a day.

Average Heavy Equipment Cycle Time

The concept of average cycle time in this study refers to the mean duration required to complete a cycle of operations, such as loading and unloading, by heavy equipment. Equation (9) can be used to determine the average cycle time.

$$\overline{Ct} = \frac{Ct \times 24}{WE} \tag{9}$$

where $\overline{Ct}$ (min) is the average cycle time, Ct (min) is the cycle time, dan WE (hour) is the adequate time available for the equipment.

Daily Actual Productivity of Heavy Equipment

The daily actual productivity formula for excavators and dump trucks can be determined by calculating the amount of actual productivity (QA) Multiplied by the time of working hours in 1 day for each heavy equipment [51]. Equation (10) can be used to determine the actual daily productivity.

$$QAH = QA \times 24 \tag{10}$$

where QAH (bcm/day) is the actual daily productivity of the equipment and QA (bcm/hour) is the actual productivity of the equipment per hour

Statistical Tools

SPSS 22 and Origin 2024 software were used for statistical analysis, focusing on equipment efficiency, cycle time, and daily productivity. Descriptive statistics were used to summarize the data characteristics, while linear regression analysis was applied to examine the relationship between rainfall duration and equipment performance.

RESULT AND DISCUSSION

Project Overview

In general, the main activities of coal mining include stripping the topsoil layer, overburden, and coal extraction. However, the scope of this research is limited to the mechanical soil removal of the overburden layer in the North TBR pit area of PT BUMA. They are using a PC2000-8 Komatsu excavator and an HD785-7 Komatsu dump truck.

Population and Sample

This study uses a population of heavy equipment types of excavator PC2000-8 Komatsu and dump truck HD785-7 Komatsu operating in TBR-OPD Pit 3 PT BUMA job site GEO-AJE. The PC2000-8 Komatsu excavator has a population of 4 units, while the HD785-7 Komatsu dump truck has 29 units. Through calculations using Equation (1), the minimum number of cycle time samples required in this study can be determined with a tolerance limit of 5%. Based on these calculations, excavators require a minimum of 4 samples, while dump trucks require a minimum of 27 samples. However, the sample data used in this study includes 1024 cycle time data for both types of heavy equipment, with a data collection period of 29 days. However, the sample data used in the data analysis process and subsequent processes only use data from 28 days because, on Wednesday, April 26, 2023, there was an anomaly in the form of very heavy rainfall.

Heavy Equipment Loading Method

The loading method applied in the mechanical earthmoving process of the overburden layer in the North TBR Pit of PT BUMA job site GEO-AJE is the 90˚ bench loading method, often used due to its higher flexibility. During the loading process, the PC2000-8 Komatsu excavator must load into the HD785-7 Komatsu dump truck vessel four times to reach the pile capacity of 42 bcm. The excavator's loading rate was set at 125% of capacity, with a total capacity of 10.5 bcm, so one excavator could pair up with eight dump trucks to achieve the optimal target. Figure 3 shows the loading process of a Komatsu PC2000-8 excavator against a Komatsu HD785-7 dump truck.

FIGURE 2. Heavy equipment loading process

Cycle Time of Heavy Equipment

In calculating the cycle time (Ct) For heavy equipment, using Equation (2) and Equation (3) with the calculation results can be seen in Table 4 for excavators and Table 5 for dump trucks. The results of Excel data processing show that in 29 days, the amount of data collected reached 1024 data. I recorded the highest daily cycle time on Saturday, April 29, 2023, with a duration of 32.32 minutes. Increased rainfall before the observation affected tool efficiency and adequate time, causing problems in some areas. In contrast, the lowest cycle time was recorded on Saturday, April 18, 2023, with 22.69 minutes, when field conditions were normal. The average cycle time over the period was 25.77 minutes.

Descriptive Statistical Analysis

Descriptive statistical analysis is an essential stage in processing data, providing an initial description of each variable in the study. This study analyzed six variables, five as dependent and one as independent. The dependent variables include the efficiency and average cycle time of Komatsu's PC2000-8 excavator and HD785-7 dump truck and their daily productivity. Meanwhile, the independent variable was rainfall duration. The analysis was conducted using SPSS 22 software, and the results are presented in Table 1.

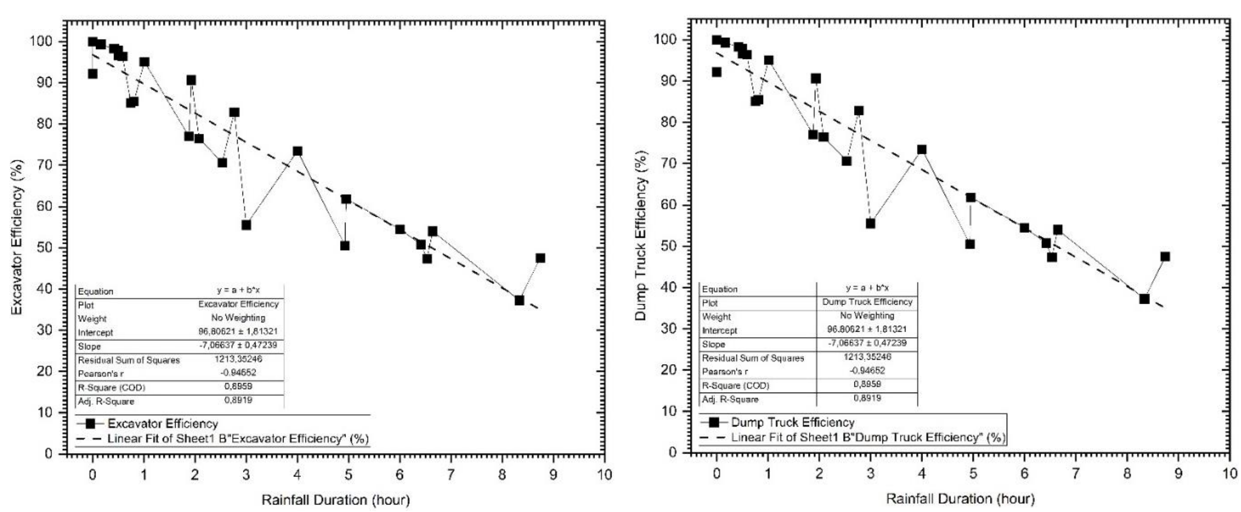
TABLE 1. Descriptive statistical analysis results

	N	Minimum	Maximum	Mean	Std. Deviation
Heavy Equipment Efficiency	28	37.29	100.00	77.7611	20.77770
Excavator Average Cycle Time	28	0.89	2.64	1.3471	0.46522
Dump Truck Average Cycle Time	28	22.83	86.86	36.5193	14.01036
Excavator Daily Actual Productivity	28	5732.20	17020.48	12344.4307	3464.88893
Dump Truck Daily Actual Productivity	28	696.28	2649.36	1839.2968	535.99810
Rainfall Duration	28	0.00	8.74	2.6950	2.78290
Valid N (listwise)	28				

There are some critical findings Based on the descriptive statistical analysis results. Machine efficiency varied from 37.29% to 100.00%, averaging about 77.76%. The variability in excavator efficiency was relatively low, indicating consistency in machine performance. The excavator's daily cycle time ranged from 0.89 to 2.64 minutes, while the dump truck's daily cycle time varied from 22.83 minutes to 86.86 minutes. The average excavator cycle time was about 1.35 minutes, while the dump trucks had an average daily cycle time of about 36.52 minutes. In addition, the daily productivity of the excavator ranged from 5732.20 bcm/day to 17020.48 bcm/day, with an average daily productivity of 12344.43 bcm/day while the dump truck had a daily productivity between 696.28 bcm/day to 2649.36 bcm/day, with an average daily productivity of 1839.30 bcm/day. Rain duration varied from 0.00 to 8.74 hours, averaging about 2.70 hours. All variables showed consistent and low variation, indicating measurement stability and machine performance consistency over the study period.

Relationship between Efficiency and Rainfall Duration

Based on data in Figure 3 (a) and (b), it can be seen that the efficiency of excavators and dump trucks tends to decrease as the rainfall duration increases. The results of the linear regression analysis show that cycle time and rainfall duration negatively correlate with excavator efficiency at 89.59% and dump truck efficiency at 89.59%. The linear regression equation for excavator efficiency is $y = 96.80621 - 7.06637X$, This means that every 1-hour increase in rainfall duration will reduce excavator efficiency by 7.06637%. The linear regression equation for dump truck efficiency is $y = 96.80621 - 7.06637X$, This means that every 1-hour increase in rainfall duration will reduce dump truck efficiency by 7.06637%.

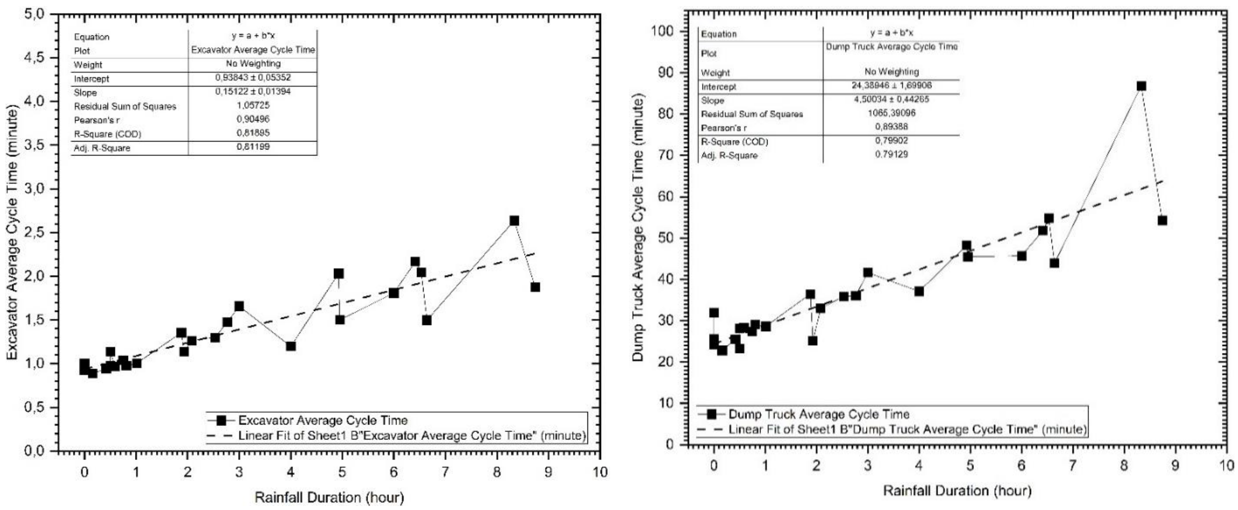


(a) (b)

FIGURE 3. Relationship between efficiency and rainfall duration

Relationship between Average Cycle Time and Rainfall Duration

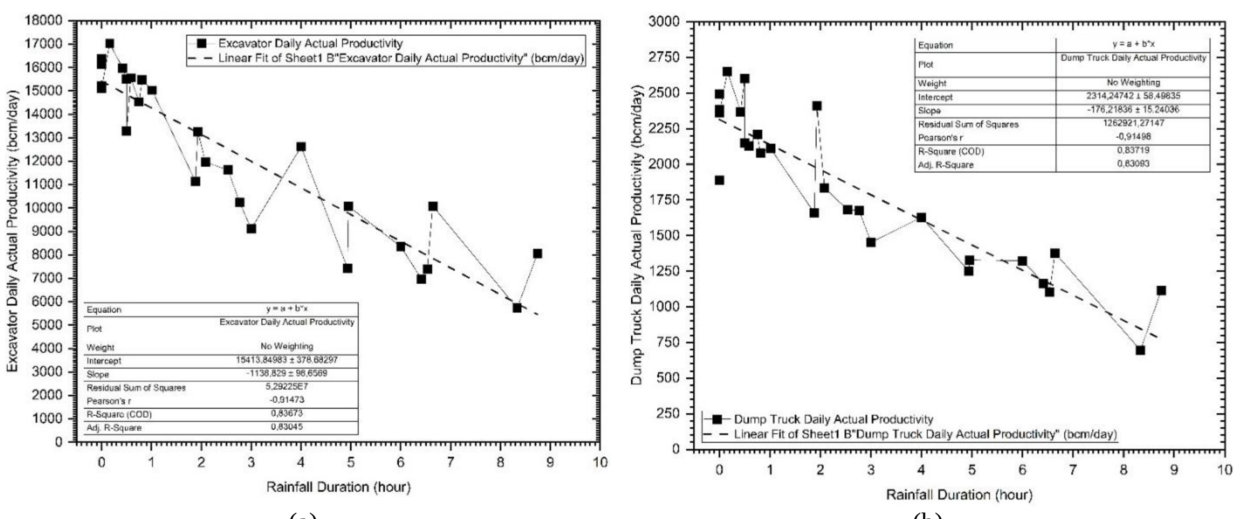
Based on the data in Figure 4 (a), it can be concluded that the average excavator cycle time tends to increase as the rainfall duration increases. Linear regression analysis shows that cycle time and rainfall duration positively correlate with a percentage of 81.90%. The linear regression equation is $y = 0.93843 + 0.15122X$, This indicates that every 1-hour increase in rainfall duration will increase the average excavator cycle time by 0.15122 minutes. Meanwhile, based on the data in Figure 4 (b), the average cycle time of dump trucks also tends to increase as the rainfall duration increases. Linear regression analysis shows that cycle time and rainfall duration have a positive correlation of 79.90%. The linear regression equation is $y = 24.38946 + 4.50034X$, This means that every 1-hour increase in rainfall duration will increase the average dump truck cycle time by 4.50034 minutes.



(a) (b)

FIGURE 4. Relationship between average cycle time and rainfall duration

Relationship between Daily Actual Productivity and Rainfall Duration



(a) (b)

FIGURE 5. Relationship between daily actual productivity and rainfall duration

Based on the data in Figure 5 (a), it can be concluded that the actual daily productivity of excavators generally decreases as rainfall duration increases. Linear regression analysis shows that productivity and rainfall duration negatively correlate 83.67%. The linear regression equation is $y = 15413.84983 - 1138.82900X$, This means that every 1-hour increase in rainfall duration will reduce the daily actual productivity of the excavator by 1138.82900 bcm/day. Meanwhile, based on the data in Figure 5 (b), the actual daily productivity of dump trucks also tends to decrease as rainfall duration increases. Linear regression analysis shows that productivity and rainfall duration negatively correlate 83.72%. The linear regression equation is $y = 2314.24742 - 176.21836X$, This indicates that every 1-hour increase in rainfall duration will reduce the actual daily productivity of the dump truck by 176.21836 bcm/day.

Results of Analysis of the Effect of Rainfall Duration on Heavy Equipment

Based on data analysis, the impact of rain duration on heavy equipment performance is as follows. Rain duration affected excavator and dump truck efficiency by 89.59%, with a linear regression equation. $y = 96.80621 - 7.06637X$. Rainfall duration affected the average excavator cycle time by 81.90%, with a linear regression equation. $y = 0.93843 + 0.15122X$. Average dump truck cycle time was affected by rainfall duration by 79.90%, with a linear regression equation. $y = 24.38946 + 4.50034X$. The actual daily productivity of excavators is affected by rainfall duration by 83.67%, with a linear regression equation. $y = 15413.84983 - 1138.82900X$. The daily productivity of dump trucks is affected by rainfall duration by 83.72%, with a linear regression equation. $y = 2314.24742 - 176.21836X$.

The findings suggest that rainfall significantly impacts the efficiency and productivity of heavy equipment in mining operations. For practitioners, this implies a need for adaptive scheduling strategies that consider weather forecasts to optimize equipment utilization. The increase in cycle time during rainy periods underscores the importance of preemptive maintenance to reduce delays. Furthermore, these results could help develop predictive models for equipment management, contributing to more efficient resource allocation in large-scale mining projects.

CONCLUSION

This study explores the impact of rain duration on the productivity of excavators and dump trucks at TBR North Pit, GEO-AJE worksite of PT BUMA. The main findings show that rain duration significantly affects the efficiency, average cycle time, and actual productivity of both types of machines. This study contributes to filling the knowledge gap by highlighting the lack of previous research that considers this factor. However, it must be recognized that this study has limitations, such as focusing on one location and a specific period. Therefore, the recommendation for future research is to expand the area and time and use more complete primary data to strengthen the findings. Thus, this study provides new insights and highlights the need for further research to understand the impact of extreme weather on the mining industry.

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