Technical analysis of shovel working time towards inter-burden production achievement in open-pit coal mine

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Abstract. Shovel production can be affected by several factors, such as shovel working time and working conditions. The shovel production for the inter-burden removal target did not achieve at mining operations in Melak, East Kalimantan. This study's main objective is to find the causes of the inadequate production and the efforts to improve. In this case study, the high delay due to the waiting for truck maneuvering caused the lack of shovel production. Some corrections were needed on the width of the loading point, and the loading method required to be replaced with double-side loading. Changes in the width of the loading point and loading method have an impact on increasing shovel productivity. In addition, a digger working time simulation is performed based on secondary data. Calculation of total production achievement is based on the simulation of time categories with working, standby, and repair time variables.

1. Introduction
In the mining production system, a shovel is paired with some dump trucks [1]. Interburden stripping and removal in open pit coal mining at a company located on Melak, East Kalimantan, used a shovel as digging and loading equipment. It takes an essential role in mining production [2]. This activity was located on loading point Pit K/LK, and the material will be moved to a dumping point Dump J3 (Figure 1). The type of shovel used was the Hitachi 2500. The production target for a shovel was 297,718 BCM, and the productivity target was 850 BCM/hour. Based on the actual data, the average shovel productivity for 3 (three) months before this research was only 716.7 BCM/hour. Several factors affect productivity achievement [3]. One of the factors was the inefficiency working time of the shovel [4]. The amount of unproductive time will result in the inefficiency of the scheduled working time for the shovel [5]. Time inefficiency also means the delay occurred in shovel production because of waiting times [6]. The other problem was inefficient working time from the scheduled time and low effective utilization [7]. It was a problem in mining operations and causing a low amount of productivity or production achievement [8].

In actual condition, there was a problem in the loading point dimension. The width of the loading point area was not ideal for mining equipment working. The lack of loading point width affected the dump truck maneuvering. It caused the shovel must wait for the dump truck maneuver, and these technical matters affected the shovel's delay time [9]. This study was conducted on March-May 2020 to make improvements in the shovel working area. An experiment to change loading area width was conducted directly in the loading point area as an improvement effort [10].
Furthermore, it was also changing the loading method from single-side loading to double-side loading. Besides that, a time categories simulation was conducted to determine how much production can be achieved by a shovel with good time management. The simulation of time categories was run by 2 (two) scenarios, time categories based on company plans and time categories based on average historical data from March 2019-February 2020. The shovel working time comprises repair time, standby time, and working (operational) time, which is related to the parameters of the mining equipment availability both mechanically and operationally [11]. These improvement efforts can increase shovel production in the mining process [12]. This research is the first time conducted in this mining area. The new overburden loading method with double-side loading will be applied at the mining site, so preliminary research is needed.

![Figure 1. Layout shovel working area location for stripping and removal inter-burden from Pit K/LK to Dump J3 (without scale)](image)

2. Methods
The research began with observation and data collection in the mining area for 3 (three) months in March-May 2020. The data obtained from direct observations are cycle time and delay time during the shovel operation. Also, there was some documentation in the form of photos of shovel operations in the research area. Cycle time data was collected using a stopwatch by observing the time it takes to perform each working cycle of the shovel. A shovel's working cycle time comprises digging, swing load, loading, and swing empty activities (Figure 2). Delay time data was collected using a stopwatch by observing some activities of the shovel that could make inefficiency working time. In other ways, the delay time of the shovel was the time it takes to perform a working activity apart of 4 (four) working cycles. In this
research, the delay time categories for shovel comprises waiting for maneuvering dump truck in loading point, shovel reposition, and waiting for loading point maintenance by dozer. Data observation was carried out throughout 1 (one) work shift, for 12 hours from 06.00-18.00 Central Indonesian Time (zone).

![Diagram of shovel working cycle](image)

**Figure 2.** The shovel working cycle comprises of 4 (four) cycle

Digging time is the time when the bucket starts reaching the pile of material to be excavated. Swing load time is the time when the bucket swings towards the dump truck vessel. Loading time is when the bucket loads material into the vessel, and empty swing time is when the bucket swings towards the pile of material after it has finished loading the vessel. Cycle time is the sum of the four-cycle times for the excavator (Equation 1). Variable $t_1$ is digging time, $t_2$ is swing load, $t_3$ is loading time, and $t_4$ is swing empty [13]. Cycle time units are expressed in minutes.

$$C_t = t_1 + t_2 + t_3 + t_4$$  

The following primary data is the delay time that occurs in the digging and loading operation. The delay time category followed the decision set by the company. Delay time data was recorded using a stopwatch and carried out in the loading point area. Delay time occurs while the shovel was working as the appropriate working cycle. Delay categories of this research were: maneuvering dump truck in loading point, shovel reposition, and waiting for loading point maintenance by dozer. Delay time is expressed in minutes. The total delay time is the sum of all delay time categories. Delay time is used to find the value of work efficiency as a correction for shovel productivity. Where $ewt$ is the effective working time used for production as the shovel working cycle, and $dt$ is the delay time, work efficiency is calculated using equation (2). The value of work efficiency ($e$) is expressed as a percentage [5].

$$e = \frac{ewt}{ewt+dt} \times 100\%$$  

In supporting analysis to be more comprehensive, this research also used secondary data from the literature, previous researchers, or company archives to complement the primary data. Some secondary data in this study are shovel specifications, payload, and historical data on shovel time categories according to repair, standby, and working time. Shovel time categories data was historical data for the past 1 (one) year from March 2019-February 2020.

The type of material in this loading point area was clay. The bucket capacity in this study was the actual capacity in loose cubic meter (LCM) which was calculated using equation (3). The variable $py$ is the average payload (ton), and $\rho_l$ is the loose material density [14]. In this research, bucket capacity ($k$) is 7.79 LCM, with $py$ is 18.22 ton and $\rho_l$ is 2.34 ton/m$^3$.

$$k = \frac{py}{\rho_l}$$  

The number of $sf$ in this study is 1.01 based on actual observations in the field. Based on laboratory tests, the clay material at the research location has an in-situ density ($\rho_i$) of 2.32 ton/m$^3$ and $\rho_l$ is 2.34 ton/m$^3$. The actual $sf$ is calculated by using equation (4).
\[ sf = \frac{p_l}{\rho_i} \]  

The actual productivity is calculated using equation (5), where \( p \) is productivity (BCM/hour), \( C_t \) is cycle time (minutes), \( k \) is bucket capacity (LCM), \( sf \) is a swell factor, and \( e \) is work efficiency [15].

\[ p = \frac{60}{C_t} \times k \times sf \times e \]  

Actual production (\( P \)) is calculated using equation (6). Production is calculated based on the \( p \) value, \( CT \) or calendar time, and \( EU \) or effective utilization. The \( EU \) is calculated using equation (7) based on the repair time (\( R \)), standby (\( S \)), and working (\( W \)) time variables [8]. \( EU \) is expressed as a percentage.

\[ P = p \times CT \times EU \]  

\[ EU = \frac{W}{W+R+S} \times 100\% \]  

After obtaining productivity and production according to actual existing conditions, the next step is to make corrections at the loading points width and loading methods, which will affect the truck maneuver time. So that changes in the maneuvering time of the truck will impact the delay time on the shovel. The delay time obtained from the correction of the loading point area is used to evaluate the productivity achievement of the shovel.

\[ Turning\ radius = 2 \times \{truck's\ length + (0.5 \times distance\ between\ the\ front\ of\ the\ truck\ body\ and\ the\ center\ of\ the\ truck's\ front\ tires)\} \]  

Then, a simulation of time categories was conducted to predict the amount of total production. The simulation of shovel time is based on categories \( W \), \( R \), and \( S \). The simulation is carried out based on the time categories of the shovel according to actual historical data for 1 (one) year from March 2019-February 2020 and the company plan. Based on each correction, production results will be evaluated to determine which correction method is most effective for increasing productivity and production of the shovel.

3. Result and Discussion
This study wants to see the impact of improving the working time of shovel on achieving production targets. Improvement efforts that result in this study are to conduct experiments on changes in the width of the loading point and changes in loading methods.

3.1. Cycle and delay time
Table 1 shows the cycle time of the shovel. The data cycle time of the shovel is the average taken for a one-month observation. The results were shovel cycle time of 0.43 minutes and delay time of 0.6 minutes.

| Cycle          | Cycle Time (minutes) | Delay (minutes) |
|----------------|----------------------|-----------------|
| Digging        | 0.68                 |                 |
| Swing load     | 0.55                 |                 |
| Loading        | 0.29                 |                 |
| Swing empty    | 0.52                 |                 |
| **Total**      | **2.04**             | **0.93**        |

The delay along cycle time was dump truck maneuvering, shovel repositioning, and waiting for loading point preparation by dozer. The average cycle time was 2.04 minutes. The average total delay was 0.93 minutes. The average total delay due to dump truck maneuvering was 0.53 minutes, and the other delays were 0.40 minutes.
3.2. Actual Productivity

The actual condition means that the shovel working time has not been corrected by changing the loading point width and loading method. The data used to calculate the number of productivity were primary and secondary data following actual conditions. Based on the calculation with equation (5), the actual productivity number of the shovel was 753.52 BCM/hour. The amount of e was 2.04 minutes (Ct) and dt was 0.93 minutes so that the actual e value is 69% (equation 2). Other variables for calculating productivity: k was 7.79 LCM and sf was 1.01.

3.3. Corrected the loading point width

The loading point width impacts the dump truck's maneuvering time, resulting in the shovel's delay. Before the correction, the width of the loading point in the excavation area was 16 m up to the maximum width of 25 m. Based on these conditions, a dump truck's average time to maneuver at the loading point was 0.53 minutes. Figure 3 shows some photos taken during the direct observation, and it used as primary data to describe the actual loading point condition.

![Figure 3. Loading point width before correction - without scale (source: personal documentation)](source: personal documentation)

The actual loading point width was not ideal yet. The loading point correction was carried out by calculating the turning radius based on the dump truck's dimensions: the length of the truck was 9.78 meters, and the distance between the front of the truck body and the center of the truck's front tires was 2.19 meters. The turning radius was calculated using Equation 8. Obtained a turning radius of 22 m and added a work safety distance of 5 m from the dump truck's right and left sides; the loading point's total width was 32 m (Figure 4).

![Figure 4. The illustration of loading point re-design for shovel's delay correction - without scale (source: personal documentation)](source: personal documentation)

Based on technical considerations, the loading point width was determined as 30 m with a meter-high bund wall on the left and right sides of the loading point area (Figure 5). After correcting the loading point width, the average dump truck maneuver time was 0.09 minutes. There was an 83% reduction in
maneuver time. Shorter dump truck maneuvers cause the delay time to decrease, thereby increasing work efficiency. Due to the correction of the loading point width, the work efficiency value will be 81%. It results in a productivity of 886.26 BCM/hour. Figure 5 was taken as primary data to describe the loading point condition after a correction was made.

3.4. Double side loading method

Double sideloading (DSL) is a method of loading material onto the vessel with the second dump truck that is already waiting in the parking position on the side of the shovel, so there is no waiting time for the dump truck. The DSL method experiment yield in the dump truck's maneuver time being only 0.06 minutes from the previous 0.53 minutes. The decrease in delay time was 88%. The productivity resulting from the DSL method experiment was 896.95 BCM/hour, with work efficiency of 82%. Figure 6 was taken as primary data to describe the DSL method. In this experiment, the loading point area width for the DSL method was 35 m based on the mining equipment dimension used in operation.

3.5. Time categories simulation

Time categories are divided into working time (W), standby (S), and repair (R). These variables impacted the performance parameters of mining equipment, both mechanical and operational. In this research, the performance parameter of the shovel used was effective utilization (EU) to calculate the actual production number. Simulations of time categories were carried out with two scenarios: first, substitute standby and repair times according to the actual working time data (based on historical data March 2019-February 2020), and second, substitute standby and repair times according to the company plan. Table 2 shows the shovel's time categories.
Shovel's time categories were primary data from direct observation and secondary data from the company archive; both were expressed in hrs/month (Table 2). There were 3 (three) conditions of time categories data: actual, company's plan, and historical data. The actual condition was the time categories taken while the research was conducted; the data was taken during the day shift for 12 hours from 06.00-18.00 (UTC+08:00) as the permission given. The company's plan was the shovel time categories based on engineering department plans. The historical data was average time categories from March 2019-February 2020.

In simulation terms with the company's plan scenario, there were red, black, and blue numbers. The red colours were times that adjusted from actual data to the company's plan. Meanwhile, the black colours were times that could not be adjusted from actual data because the time categories were naturally occurring events, i.e., rain, slippery after rain, and breakdown. The blue colours were the time categories in actual condition lower than the company's plan, i.e., survey and blasting, so no time adjustment was needed for the simulation scenario. The simulation scenario based on historical data from March 2019-February 2020 was adjusted by the average shovel time categories for total standby and repair time.

If there were 30 days for work in a month and the number of working shifts per day was 2 (two) shifts with 12 working hours in every shift, there would be 720 hours scheduled working time for a month. To calculate the EU parameter, first determined the working time in a month from scheduled time minus standby and repair time.

Table 2. Shovel time categories (hrs/month)

| Time categories               | Actual   | Simulation Scenarios |                      |                    |
|-------------------------------|----------|----------------------|---------------------|--------------------|
|                               |          | Company's plan       | Historical data     |                    |
| Standby time                  | 325.86   | 263.54               | 216.78              |                    |
| Operator moving to loading point | 10.67    | 0.00                 |                     |                    |
| Safety talk                   | 27.00    | 20.00                |                     |                    |
| Survey                        | 10.51    | 10.51                |                     |                    |
| Delay at dumping point        | 11.23    | 10.30                |                     |                    |
| No operator                   | 38.12    | 0.00                 | 216.78              |                    |
| Rain                          | 142.60   | 142.60               |                     |                    |
| Slippery                      | 55.17    | 55.17                |                     |                    |
| Blasting                      | 11.79    | 11.79                |                     |                    |
| Refuel                        | 15.85    | 10.58                |                     |                    |
| Change Operator               | 2.93     | 2.59                 |                     |                    |
| Repair time                   | 58.42    | 53.64                | 77.01               |                    |
| Breakdown                     | 43.06    | 43.06                | 77.01               |                    |
| Maintenance                   | 15.36    | 10.58                |                     |                    |
| Working time                  | 335.72   | 402.82               | 426.21              |                    |

Based on equation (7), the EU number is obtained for each condition, as shown in Table 2. In actual condition, EU was 47%; in simulation scenario based on the company's plan, EU was 56%; and simulation scenario based on historical data resulted in EU as 59%. The highest EU number derive from simulation scenario based on historical data. The historical data did not detail the time categories, both standby and repair. So, the shovel time on simulation scenario based on historical data could not be adjusted from actual time categories. Table 3 shows the comparison of parameter EU based on actual conditions and simulation scenarios.

Table 3. Comparison of parameter effective utilization (EU)

| Variables      | Unit       | Actual   | Simulation Scenarios |                      |                    |
|----------------|------------|----------|----------------------|---------------------|--------------------|
|                |            |          | Company's plan       | Historical data     |                    |
| Calendar time  | hrs/month  | 720      | 720                  | 720                 |                    |
| Working time   | hrs/month  | 335.72   | 402.82               | 426.21              |                    |
3.6. Production comparison

Production calculation using productivity and scheduled working time which corrected with EU parameters (Equation 6). The scheduled working time was 720 hours. The scheduled working time will be corrected to get the actual working time. The EU parameter as correction factor was calculated using equation (7), based on data in the time categories (Table 2).

Table 4 shows the production and productivity achievements. The results showed that the productivity did not reach 850 BCM/hour in actual conditions, and the production did not reach 297,718 BCM. However, after corrections were made to the loading point width and loading method, there was an increase in productivity, even exceeding the target. The DSL loading method yields the highest productivity, about 896.95 BCM/hour, and the correction can achieve the production target. The production target was achieved in both simulation scenarios even though there was no correction in loading point width or loading method. Simulation based on historical time resulted in the highest production number. However, there is a drawback in this historical data because there is no breakdown of time categories.

Table 4. Productivity and production comparison from correction and simulation

| Parameters          | Actual | Loading point improvement | DSL method | Company's plan | Historical data |
|---------------------|--------|----------------------------|------------|----------------|-----------------|
| Work efficiency, %  | 69     | 81                         | 82         | 69             | 69              |
| Productivity, BCM/hrs | 753.52 | 886.28                     | 896.95     | 753.52         | 753.52          |
| Effective utilization, % | 47     | 47                         | 47         | 56             | 59              |
| Production, BCM     | 254,993 | 299,919                    | 303,528    | 303,821        | 320,097         |

Figure 7 expresses the shovel productivity and production. The light blue bar graph expresses the achievement of production, while the dark blue bar graph expresses productivity. Both production targets and productivity were not achieved in actual conditions. Even though the EU parameter follows actual conditions, correlations in loading point width and method achieved production and productivity targets. Besides that, the production target will be achieved in conditions where there were no corrections in the loading point width or loading method, but there were efforts to correct the shovel working time by reducing the standby and repair time.
4. Conclusion
Based on this research, productivity can be achieved if improvements are made to the loading point width and changed to double-side loading. Meanwhile, in the production achievement, if there is no improvement in the loading point or loading method, it is necessary to improve the shovel working time, which is affected by standby time and repairs to the equipment. The possible correction to be implemented were improving the loading point by changing the width and loading method and reducing the shovel's standby and repair time as the company plan. In this study, the time categories based on historical data are still the overall total time. There is no more detailed time category breakdown. In the development of this research, more details can be done in the time categories so that the time simulation is based on more detailed data.

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