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Research Paper

Optimizing Coal Hauling Operations: A Strategic Plan for Increased Productivity at PT Borneo

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Abstract

The purpose of this research is to determine the key operational variables that impact productivity in PT BORNEO and identify optimal targets to improve productivity. A mixed methodology of qualitative and quantitative approaches, supported by process observation, was used to collect data. The study primarily uses existing quantitative data, but interviews may be conducted to capture constraints in the implementation plan process. GPS data is also collected via an API to obtain information about truck movements, which can be divided into various activities to identify cycle time and analyze system performance. The study found that reducing loading time and minimizing random stoppages can significantly improve productivity, with average loading time being the most important factor. Stoppage before rest time and stoppage in loaded condition and at major prayer time had little impact on overall productivity. Future research could investigate the impact of other variables such as equipment maintenance and driver training on productivity.

Keywords *Productivity, Operational variables, Optimization*

INTRODUCTION

Coal mining has been a major economic driver for many countries around the world, including Indonesia (Armis & Kanegae, 2020). PT BORNEO, a subsidiary of a local conglomerate group in Indonesia, is one of the country's top five coal producers. With an annual permitted production of 36 million tons of coal, PT BORNEO aims to become one of the largest coal mines in Indonesia. As with most mining companies, PT BORNEO follows a standard business process that starts with land clearing and ends with shipment to customers.

However, coal mining has been associated with environmental concerns, including air pollution, land degradation, and water pollution (Kalisz et al., 2022). Mining companies are often required to meet stringent environmental regulations and to ensure that their operations do not harm the environment. Additionally, the volatility of commodity prices, depleted reserves, rising costs, and changes in government regulations have forced mining companies to reassess their strategies to improve efficiency and flexibility to reap the opportunities.

In 2021, the world faced two major events that had a significant impact on the coal market: the ongoing COVID-19 pandemic and the war between Russia and Ukraine (Adolfsen et al., 2022). The pandemic caused disruptions in global supply chains, leading to shortages in some countries and an increase in demand for certain goods. One of the goods that experienced a surge in demand was thermal coal, which is used to generate electricity. At the same time, the conflict between Russia and Ukraine disrupted natural gas supplies to Europe, which caused many countries to turn to coal as an alternative source of energy (Brodny & Tutak, 2022). This led to a surge in demand for coal, which caused the price of thermal coal to soar. Indonesia, as one of the world's largest exporters of thermal coal, was no exception.

Although there are global efforts to reduce coal consumption and promote renewable energy, the idea that coal is still necessary due to the lack of economic alternatives and lower efficiency of renewable energy is a common misconception. Renewable energy sources such as

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solar, wind, and hydro have already reached economical scales and have been replacing fossil fuels in many parts of the world. Furthermore, coal is essential for the production process of steel and cement, but its use can be reduced by transitioning to alternative processes that rely on renewable energy. Finally, many countries have significant domestic reserves of coal, which are traditionally used for domestic purposes.

Previous studies have examined the impact of improving the quality of coal on productivity. Das and Sengupta (2004), found that productivity can be significantly increased by improving the quality of coal. Similarly, (Leung & Scheding, 2015) found that the quality of coal has a significant impact on productivity. Another study by (Zhang et al., 2011) examined the effects of coal-resource integration in developing countries and regions. The analysis showed that such integration projects can effectively improve mining technologies, collect capital, and encourage international cooperation and exchange. These findings provide important insights into the factors that can impact productivity and the potential benefits of coal-resource integration projects in developing countries and regions.

Based on the literature review, while previous studies have highlighted the positive impact of improving coal quality on productivity and the potential benefits of coal-resource integration projects in developing countries, there appears to be a research gap in the specific context of Indonesia. Specifically, there is a lack of research on the potential for improving coal quality in Indonesia, and the impact that such improvements could have on productivity in the country's coal mining sector. This thesis will explore the business process of PT BORNEO, a coal mining company in Indonesia, and analyze the company's strategies to improve its efficiency and flexibility in meeting the demand for coal. The study will also examine the challenges faced by PT BORNEO in terms of meeting environmental regulations and ensuring sustainability. The research aims to contribute to the understanding of the coal mining industry in Indonesia and provide insights into the strategies that mining companies can adopt to overcome the challenges they face.

LITERATURE REVIEW

Coal Hauling Process

An efficient coal hauling process is crucial to meet the production targets set by mining companies. The coal mining process has several stages, starting from the upstream activities of digging coal and processing it until it reaches the downstream stage of marketing or delivering the coal to customers. One of the most critical stages in the mining process is the coal hauling activity, which plays a vital role in maintaining a stable supply of coal products for marketing or delivery to customers. Therefore, it is necessary to evaluate the effectiveness of the coal hauling process and identify ways to optimize it.

To achieve optimal hauling productivity, the track flow should be designed to remain smooth, minimizing waiting times and queues. Efficient hauling processes rely on the seamless movement of vehicles, requiring the reduction of any obstacles along the route to enhance operational effectiveness. In this regard, PT BORNEO uses GPS-based tracking technology to monitor all activities and time-related events in the hauling process. Riyandi and Wibowo (2020) support this method, emphasizing the importance of hauling activity in the mining industry. By improving the coal hauling process, mining companies can achieve efficient and effective production to meet their targets.

Several studies have explored efforts to optimize the coal supply chain by sequencing business processes to align with shipping schedules. In the mining industry, the coal hauling process plays a crucial role, and various strategies have been proposed to enhance its efficiency. However, limited research has specifically addressed coal hauling. Therefore, this study focuses on the coal hauling process from ROM (Run of Mine) to the port at PT BORNEO, aiming to identify the challenges faced by the company and provide recommendations for optimizing the process.

This study's significance lies in its contribution to the professional world in the mining industry and other industries that use closed-loop hauling systems. It is believed that this research will lead to organizational process improvement and business sustainability for PT BORNEO in the long term. This research will help identify the factors that affect the efficiency of the coal hauling process and provide recommendations for optimizing the process. Ultimately, this study seeks to contribute to the development of a more efficient and effective coal-hauling process in the mining industry.

Hauling Truck Productivity

The productivity of hauling trucks is crucial for the efficient operation of mining industries. Several factors can affect the productivity of trucks, including the type and characteristics of soil, payload in terms of weight or volume, road grades, distance, and haul return, the efficiency and condition of equipment and workplace, and the loader's capacity/productivity. To measure truck productivity, a formula is used, which involves calculating efficiency and cycle time. Cycle time comprises several components, including loading time, loaded travel time, dump positioning time, dumping time, empty travel time, and spotting time.

According to a study by Thompson and Visser (2006), the selection of truck size and the number of trucks required to move material depends on several factors, including the type of material, haul distance, and frequency of hauls. In addition, the study suggests that the productivity of hauling trucks can be improved by optimizing the haulage route and maintaining the equipment properly.

Similarly, a study by Chaowasakoo et al. (2017) on the performance of mining equipment recommends using a fleet management system that can help optimize the routing and scheduling of trucks, reducing cycle times and idle time for loaders. The study also suggests using predictive maintenance techniques and training operators to improve the efficiency of equipment and reduce downtime.

Moreover, a study by Arteaga et al. (2018) on the selection of the optimal fleet size for an open-pit mine recommends considering the trade-off between the capital cost of equipment and the operational cost of running the fleet. The study also suggests using simulation models to evaluate the impact of different factors, such as maintenance policies and road conditions, on the productivity of hauling trucks.

Another study by Bozorgebrahimi (2004) on the impact of road design on the productivity of mining trucks highlights the importance of considering road design factors, such as grades, curves, and width, in improving truck productivity. The study suggests that optimizing road design can reduce cycle times, fuel consumption, and maintenance costs, resulting in overall productivity gains for mining operations.

In summary, the productivity of hauling trucks in mining operations depends on several factors, including equipment efficiency, road conditions, and maintenance policies. Various studies recommend using fleet management systems, optimizing haulage routes, and maintaining equipment to improve truck productivity. Additionally, the selection of the optimal fleet size and the consideration of road design factors can also contribute to the overall productivity of mining operations.

RESEARCH METHOD

Root Cause Analysis

Cause Mapping & 5 Why Method

Cause mapping is a technique that provides a visual representation of why a particular event or issue occurred. It creates a connection between individual causes and effects to unveil the system of causes behind an event. The technique is widely used in various studies as a root cause analysis tool. A cause map always starts with a deviation from the ideal or target state and is built by investigating the problem and then backing into the causes by asking why questions. A cause map is built from left to right, and the correlation between causes and effects is created through arrows that read "*was caused by*" (Putri & Susanto, 2017). The technique asks questions beginning with "*Why did this event happen?*" and continues until the cause(s) are identified. The Cause Mapping Method also includes the question, "*What was required to produce this effect?*" to build a more detailed cause map that provides a complete representation of the issue.

Control Chart

A control chart is a graphical representation of how a process changes over time. Data are plotted in time series and a central line is drawn to indicate the average, while upper and lower lines are used to indicate the control limits. These lines are determined from historical data. By comparing current data to these lines, one can conclude whether the process variation is consistent or unpredictable (Flores et al., 2020). Control charts are used in various industries to control processes by identifying and correcting problems as they occur, predicting outcomes from a process, analyzing patterns from special causes or common causes, and determining whether a quality improvement project should aim to make fundamental changes. There are many types of control charts available that can be used, depending on the nature of the process and data. The basic procedure for building a control chart involves choosing the appropriate type, selecting a suitable period for data collection, collecting and analyzing data, and looking for out-of-control signals.

Scatter Plot / Scatter Diagram

A scatter plot is a diagram that graphs pairs of numerical variables, with one variable on each axis to examine the relationship between the two variables. If the variables are correlated, the points will fall along a line or curve. Scatter plots are used when we want to compare pairs of data when the dependent variable might have multiple values for each of the independent variables when we want to find correlations between two variables, identify potential root causes of problems, or test an autocorrelation. Creating a scatter plot involves identifying the variables, determining the type of correlation between the variables, plotting the points, drawing a line of best fit, and interpreting the results (Elearn, 2021).

Hauling Truck Productivity Calculation

According to the *Mining Equipment and Material Handling* book by Mousavi & Naghdi (2013), to measure truck productivity, we can use this formula:

$$P = E \times 60 / C$$

with:

P = productivity (measurement unit (BCM)/hr)

E = Efficiency (%)

C = Cycle Time Truck (minutes)

The cycle time was calculated from the time trucks started loading at the loading point until they came back to the loading point and were ready to be loaded again. Commonly the cycle time components can be broken down into:

$$C = \textit{Cycle Time Truck} = a + b + c + d + e + f$$

a. Loading time: time for the truck to be fully loaded starting after the truck finished spotting.
b. Loaded travel time: time for truck to move from loading point to dumping point
c. Dump positioning time: time for the truck to position itself on the dumping point
d. Dumping time: time for the truck to empty all the cargo in the vessel and put the vessel again on the truck.
e. Empty travel time: time for truck to move from dumping point to loading point
f. Spotting time: time for the truck to position itself near the excavator/loader and ready to be loaded

This cycle time calculation will lead to truck number requirement calculation for moving the material nonstop from the loading point to the dumping point in such a way that the loader/excavator will have minimum idle time.

Matching Factors

Matching factor is an approach commonly used in mining to measure the matching degree between loader equipment and hauling equipment in every load and haul activity. The matching factor value lies between 0 and 1, whereas 1 means that the loader and hauler work at 100% capacity, and there is no idle time either for the loader or hauler.

There are some variations of the matching factor formula, but all compare loader capacity and hauler capacity. The matching factors that will be used in this research are:

$$MF = \frac{Nt \ x \ Cl}{Nl \ x \ Ct}\text{; where,}$$

MF = Matching Factor
Nt = number of trucks or haulers
Nl = number of diggers or loaders
Cl = cycle time of diggers or loaders
Ct = cycle time of trucks or haulers

Based on the MF's formula, there are three possibilities of value from the matching factor:

a. MF <1 means the hauler's capacity is assigned at 100% capacity while the loader works under 100% capacity. This causes the loader to wait for trucks to arrive.
b. MF = 1 means loader and hauler working at 100% of their capacity. There is no waiting time for the loader and there is no queue time for the hauler.
c. MF >1 means the hauler's capacity is assigned under 100% and the loader works at 100% capacity. This will lead to a situation where trucks will form a queue line at the loading point.

Matching factors are indirectly affected by other factors such as material type, depth of cut, swing angle, working conditions, truck capacity, bucket capacity, operator skills, and equipment condition.

Data Collection Method

For this study, a mixed methodology of qualitative and quantitative approaches was used to collect data, which was further supported by process observation. The study aims to address business problems and provide proposed solutions that are suitable for the current conditions, needs, and constraints of PT BORNEO. The research will primarily focus on evaluating the underlying causes of consistently unachieved RTP (ROM to PORT) productivity.

The first phase of the study involved identifying the problems that need to be addressed by PT BORNEO. This will be followed by the second phase, which will delve deeper into the problem and produce possible business problem scenarios. The root causes of the business problem will be identified during this phase. The third phase will determine the most feasible solution and implementation plan.

This study primarily uses quantitative data that already exists but has not been used to generate meaningful insights and solutions. Interviews may be conducted to capture any constraints in the implementation plan process. GPS data is also collected through IT-enabled means via an API, as it consists of millions of data rows. Truck movements are essential to obtain information and trends about transportation processes, including any congestion or obstacles that occur in the system. These movements can be divided into several activities, and by knowing each of these activities, the cycle time will be identified and the expected system performance can be analyzed.

Lastly, the data collected and used by the company to evaluate performance in daily or shift aggregates will be utilized. Using this data, the researchers can identify variables that may be the root cause of issues in the hauling process. Through this mixed methodology, the study aims to provide feasible solutions to improve the company's productivity and performance.

Data Analysis

Considering the quality of sensors and the possibility of noise in raw data and report data, data analysis begins with data preparation and cleaning, outlier detection, and clean data isolation. The next step is to test the assumptions that need to be met for statistical analysis. After the data is ready, the analysis will be done using statistical tools such as the Goodness of fit test, one sample t-test, paired sample t-test, spearman correlation, statical power measurement, run test, and Wilcoxon test.

Each component describes the average cycle time of the truck in each segment. In the next step, researchers will correlate each variable that potentially affects normal cycle time. Any significant variables will be isolated for the verification step. From this last step, it can be concluded which variables truly contribute to the unachieved performance. The final stage of this study formulate proposed solutions to improve performance and tools to detect and predict performance deviations from normal conditions or to detect changes from normal conditions in operations so that performance can be maintained in optimal conditions.

FINDINGS

In this analysis, the first step is to translate the actual process into an analysis model that represents the system. The tracking system is designed to use geofences at every 500 meters. With the decent GPS quality, there are many unstable GPS traces in the data. To obtain more meaningful information from the data, an aggregate model that removes unstable GPS while retaining the GPS data's significance and capturing relevant information must be created.

In the analytical model, there are two routes in the system. One is built, owned, and maintained by PT BORNEO (blue line), and the other is built, owned, and maintained by another company (green line). The cost of using the green route is much higher than the blue PT BORNEO-owned route, limiting movement using the green route in terms of cost savings and capacity. The road also only supports from ROM EST to KM12 and from KM12 to PORT-T, with no other entry or exit points. In the analytical model, there are six ROMs and two PORTs that can be used to transfer coal commodities from ROM to PORT. POOL is a term used by transport companies as a place for their operational crews to carry out operational activities such as shift changes, rest time, minor repairs, etc. Some of them combine their POOL with the workshop, where they can carry out major maintenance or other activities that require trucks to be unloaded.

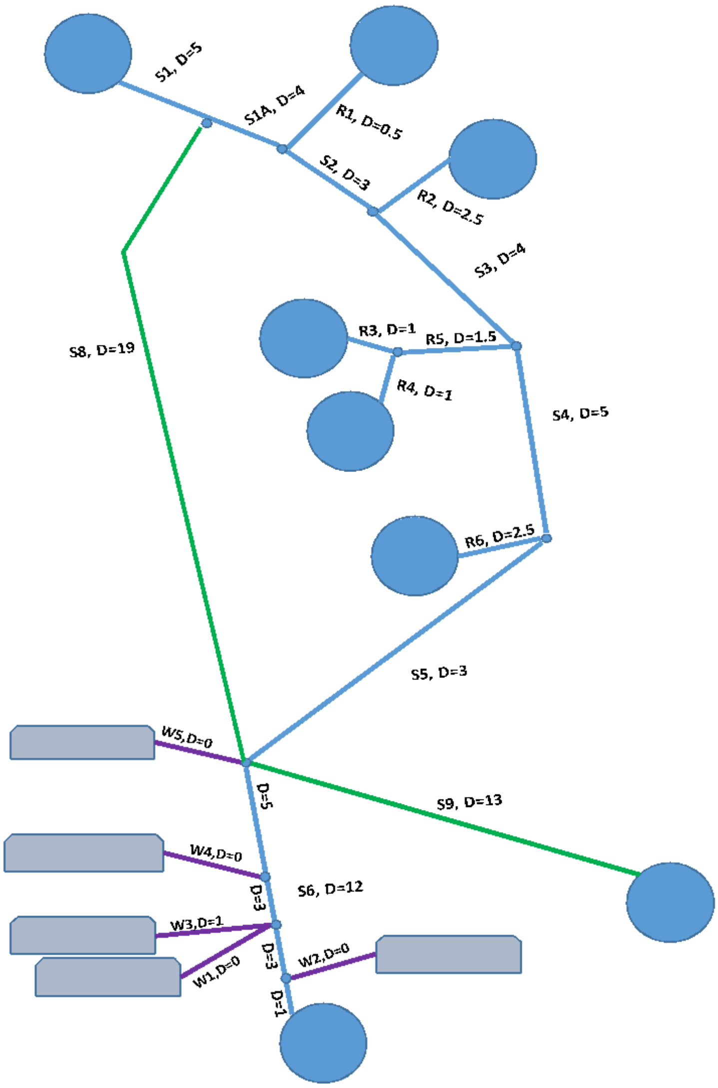


Figure 1. Hauling Road Network

The analytical model divides the road with major intersections where the main road splits or merges (denoted by S) (Figure 1). There are two roads in the system. One was built, owned, and maintained by PT BORNEO (blue line), and the other was built, owned, and maintained by another company (green line). The cost to use green roads is much more expensive than the Blue Line road owned by PT BORNEO so movement using the Green Line road is limited in terms of saving cost and capacity.

The distance of the main road varies between one (1) and thirteen (13) kilometers. Some minor sections from ROM are symbolized by R, while minor sections that connect the Pool with the main road are symbolized by W. The distances of R and W are very short, all less than 3 km. To determine the root causes of business problems for the transport company, researchers will employ root cause mapping and the 5-why method. These methods help identify multiple possible underlying causes. Each of these root causes must be verified either by observation or by collecting data that justifies and confirms the causal relationship with the business problem. One root cause may cause several problems, but it does not mean that the root cause is the main cause. Each potential root cause should be treated the same until proven otherwise.

From the problem tree mapping below (Figure 2), several potential root causes could be the main cause of low transporter productivity due to their possible systematic nature in the business. Factors that affect all trucks in the system will not be considered as root causes because when that happens, all trucks will stop, and there will be no production at the appropriate time, such as flooding, social issues, etc.

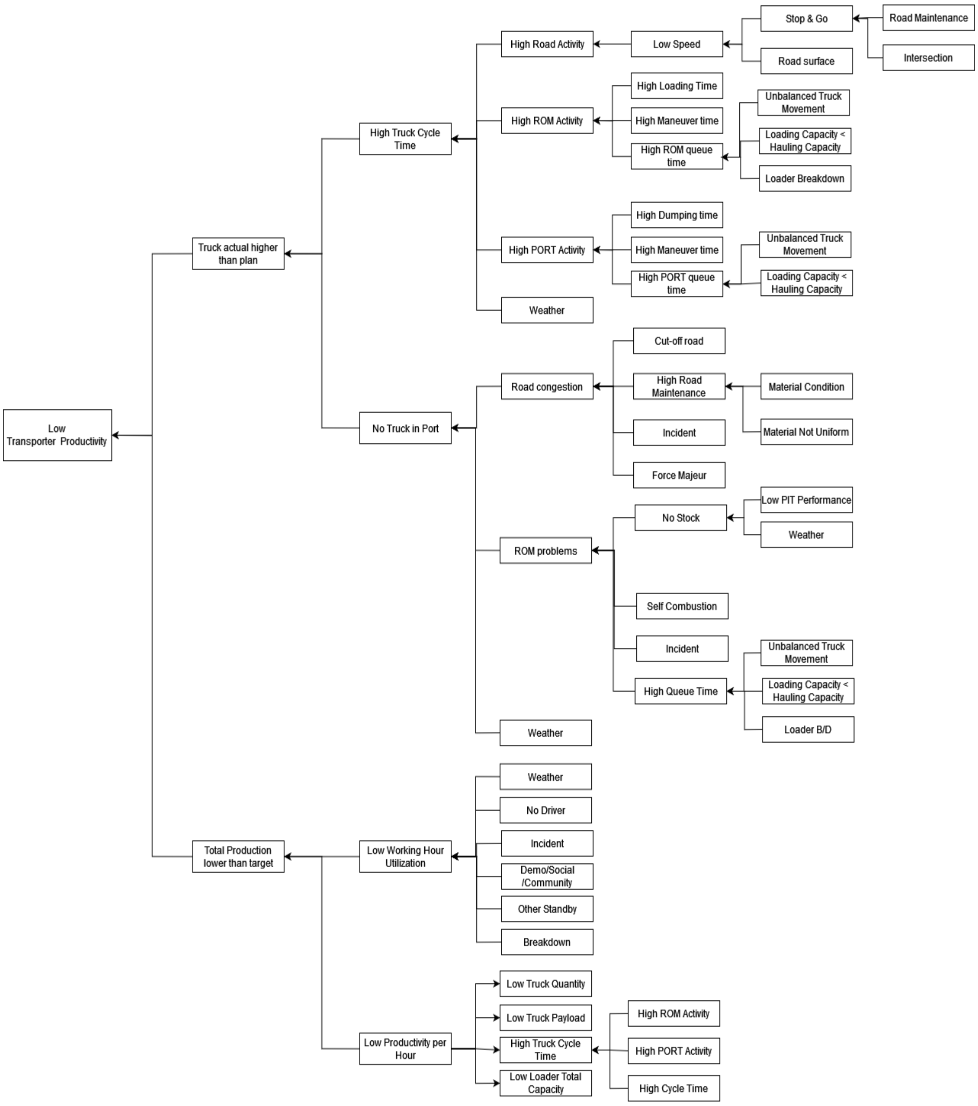


Figure 2. Mapping Diagram for Low RTP Productivity

The empty and loaded cycles are built by adding all main road sections for different conditions (empty and loaded). The queue at the ROM will be approached by counting trucks at each ROM minus the ROM's output. ROM activities will be measured by direct observation and will be used as verification for ROM output calculations. The queue at the PORT uses the same approach method as the ROM. The loaded and empty cycles will be affected by many factors, and these factors will be represented by standard variations in the loaded and empty cycles. All time used by trucks from the loaded cycle and return to ROM activities will be the truck cycle time (Table 1).

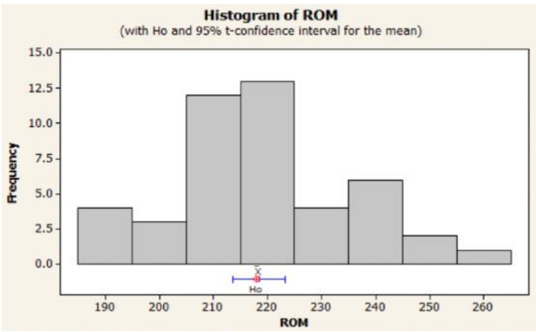
Table 1. Average Time per Segment (minutes)

Segment	Distance km	Shift 1 Empty	Shift 1 Loaded	Shift 2 Empty	Shift 2 Loaded
S1	5	48.7	39.6	51.6	44.1

Segment	Distance km	Shift 1 Empty	Shift 1 Loaded	Shift 2 Empty	Shift 2 Loaded
S1A	4	21.6	50.7	14.6	59.5
S2	3	3.8	4.1	4.2	4.4
S3	4	4.7	5.7	5.1	6.3
S4	5	6.3	8.2	6.9	9.1
S5	3	4.5	4.5	4.7	4.9
S6	12	9.8	29.6	10.1	26.1
S7	19	17.0	24.3	17.9	25.9
S8	13	7.5	3.5	7.5	3.7
R1	0	0.0	0.0	0.0	0.0
R2	2.5	4.0	4.9	4.3	5.7
R3	1	1.3	1.6	1.5	2.2
R4	1	2.4	3.8	2.6	4.1
R5	1.5	2.0	3.4	2.2	3.9
R6	2.5	3.3	5.5	3.5	6.0

ROM and Port Activity

The findings of the study showed that the normal ROM activity time for loading coal onto trucks was found to be an average of 218 seconds. This was inferred using 1 sample t-test hypothesis testing, which did not provide enough evidence to accept H1 (≠218 seconds) with a p-value of >5% (Figure 3). On the other hand, the normal PORT activity time for unloading coal from trucks and delivering it to the stockpile or transferring it to barges was found to be an average of 92 seconds. Again, this was inferred using 1 sample t-test hypothesis testing, which did not provide enough evidence to accept H1 (≠92 seconds) with a p-value of >5%.

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Test of mu = 218 vs not = 218

Variable   N    Mean  StDev  SE Mean        95% CI          T      P
ROM       45  218.44  15.94     2.38  (213.66, 223.23)  0.19  0.852
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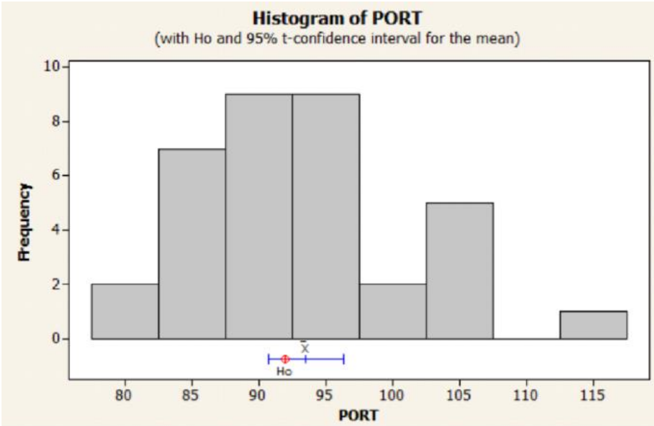
Figure 3. T-test sample for observation of ROM data

However, some anomalies were observed during the study that caused the PORT output to slightly decrease. Certain trucks were waiting for the dump body to be perfectly aligned with the body frame before moving forward, which is an ideal practice but not the best practice for reducing cycle time. To reduce cycle time, trucks usually move forward when the dump body is only halfway into the body frame. Additionally, some hoppers dedicated to double trailer dump were only being dumped by a single truck at a time, which presents an opportunity to further reduce cycle time in coal hauling operations.



Test of mu = 92 vs not = 92

Variable	N	Mean	StDev	SE Mean	95% CI	T	P
PORT	35	93.51	8.22	1.39	(90.69, 96.34)	1.09	0.283

Figure 4. T-test for observing PORT data

ROM and Port Queue

The study analyzed the factors affecting the productivity of the RTP in Indonesia, specifically the impact of the number of hauling trucks on productivity. The study found that the number of trucks had a strong positive correlation with productivity per shift. However, the relationship was not linear, indicating that the trucks had reached the road limit, and additional trucks would lead to lower output for one input unit. This phenomenon is known as diminishing marginal returns. Based on the findings, it is suggested that the company should monitor truck quantity closely and not add any more trucks into the system.

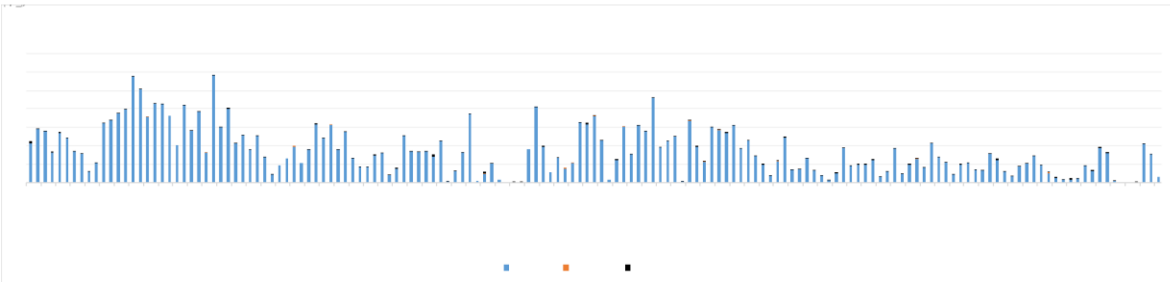


Figure 5. Average Queue at PORT

The study also examined the truck quantity per hour and found that there were significant differences in truck quantity at certain times, such as during fatigue time (3 to 5 AM), post-change shift time (6 to 8 AM and 6 to 8 PM), and near change shift time (3 PM to 6 PM). The method of changing shifts resulted in drivers assembling at a certain point, which caused a loss of time. The statistical test results showed that there were significant differences in truck quantity at specific hours, which suggests that it is important to monitor and manage the number of trucks during those hours to ensure optimal productivity.

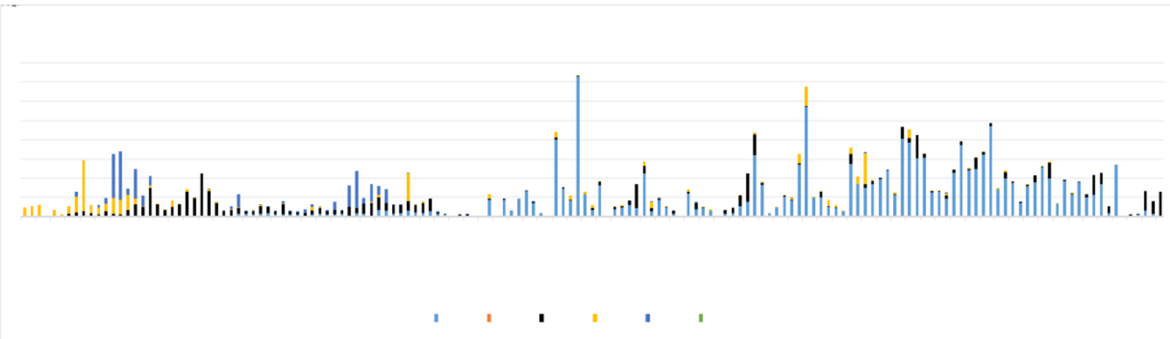
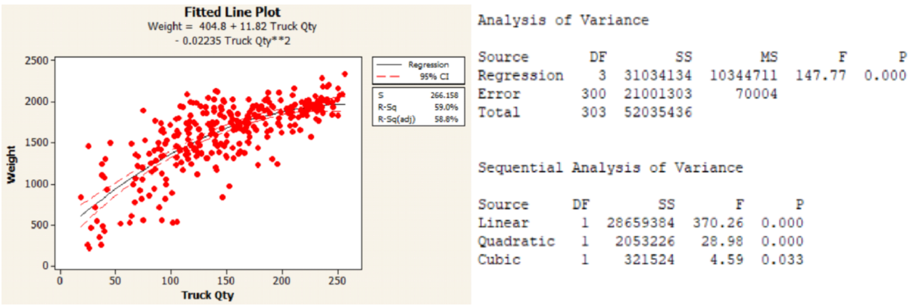


Figure 6. Daily Average Total Queues in ROM

In addition, the study found that there were other delays that caused a loss of time in production activity, which were unidentified because each truck had unknown details. Therefore, it is important to conduct further research to identify these delays and address them accordingly to improve productivity. Overall, the study highlights the importance of monitoring and managing the number of hauling trucks and identifying and addressing delays that cause loss of time to ensure optimal productivity in the RTP in Indonesia.

Truck Quantity

The researchers found that the quantity of trucks used to transport coal to the port is another factor that affects the productivity of the RTP. However, the movement of hauling trucks can vary due to various causes, such as breakdowns, refueling, driver rest times, regular check-ups, GPS intermittent signals, and other unforeseeable delays. Despite these delays, the number of trucks that are effectively operating on the haul road should be kept constant or at least meet a certain quantity in every operational hour.



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	31034134	10344711	147.77	0.000
Error	300	21001303	70004		
Total	303	52035436			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	28659384	370.26	0.000
Quadratic	1	2053226	28.98	0.000
Cubic	1	321524	4.59	0.033

Figure 7. Truck quantity and productivity relationship

Based on the visual tracking data, the researchers found visible trends where trucks tend to exit the system during change shift time between 5.00 to 6.00 WITA and 17.00 to 18.00 WITA, during prayer time especially between 15.00 to 16.00 WITA and between 2.00 to 3.00 WITA, and near rest-time in 12.00 and 23.00 WITA. However, other delays cause loss of time in the production activity which are unidentified because each truck has unknown details.

As a benchmark based on the planning process, the researchers estimated the number of trucks per shift equivalent to the actual trucks that perform full-time production activity. They estimated the quantity using a weighted average with time fraction in the data as the weight, resulting in a relationship between truck quantity and productivity per shift as shown in Figure 8.

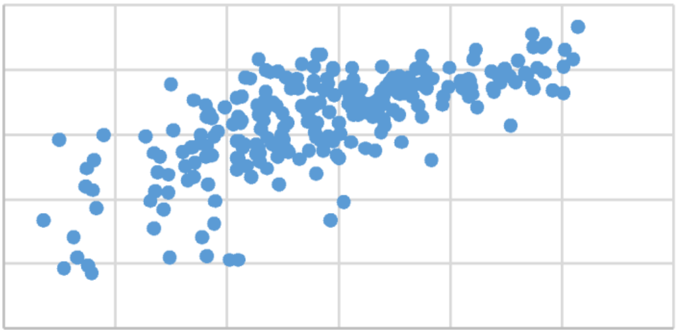


Figure 8. Truck quantity compared with productivity.

The scatter plot in Figure 9. shows that there is a strong positive correlation between truck quantity and productivity per shift. However, this relationship is not linear and can only be explained by a quadratic or cubic equation. Linear regression can only explain around 55% of the data, while quadratic and cubic equations can explain around 59% of the data. However, the cubic fitting resulted in an increased p-value without a significant increase in R-square, suggesting that the truck quantity is already reaching the road limit, and any additional trucks will result in lower output for one input unit. This phenomenon is commonly known as diminishing marginal returns. At the current capacity, it would be better if the company monitors the truck quantity closely and does not add any more trucks to the system.

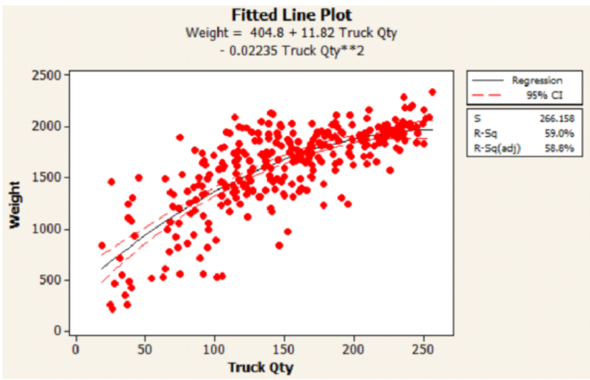


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Figure 9. Truck quantity with productivity relationship

To further analyze the truck quantity trends, the researchers isolated the truck quantity in each hourly time slot and compared it with the next time slot. Using 3 months of data, this study found that there are significant differences in truck quantity during certain hours. For example, during fatigue time from 3 to 5 AM, many drivers are slowing down or taking a rest along the road. At 6 to 8 AM, which is the post-change shift time, many drivers are just starting to enter the system gradually and do the production process. Another significant difference occurs during non-Friday time from 3 PM to 6 PM, which is a narrow time combining short prayer time at 3 PM, followed by near change shift time at 5 PM and 6 PM (Table 2). The method of changing shifts makes drivers assemble at a certain point, resulting in a loss of time.

Table 2. Statistical test for Truck Quantity per Hour excludes Friday

hour_before	hour_after	statistics	p_value	result
0	1	7311.5	0.1907	Same
1	2	6681	0.2964	Same
2	3	6680	0.0566	Same
3	4	6453.5	0.0005	Not Same
4	5	5888.5	0.0000	Not Same
5	6	7713.5	0.4316	Same
6	7	4326.5	0.0000	Not Same
7	8	6485	0.0101	Not Same
8	9	7412	0.3927	Same
9	10	7022.5	0.4569	Same
10	11	6129	0.4742	Same
11	12	7832	0.2720	Same
12	13	7584	0.4273	Same
13	14	7248.5	0.4478	Same
14	15	6923	0.1253	Same
15	16	7218.5	0.0132	Not Same
16	17	6862	0.0315	Not Same
17	18	7415	0.0183	Not Same
18	19	5930.5	0.4919	Same
19	20	7027	0.0578	Same
20	21	5275	0.2952	Same
21	22	6810.5	0.4742	Same
22	23	6449.5	0.1644	Same
23	24	4454	0.0913	Same

The statistical test in Table 2 shows the comparison of truck quantity per hour between the hours before and after. The test excluded Friday because Friday is a special day in Indonesia, and there is a longer stoppage time. The statistical test shows that there are significant differences in truck quantity during certain hours, such as during fatigue time from 4 to 5 AM and during post-change shift time from 6 to 7 AM, and between 3 PM to 6 PM, except for the hour before 3 PM. This analysis helps the researchers identify the hours with significant differences in truck quantity and may be useful for optimizing the scheduling of trucks to improve the productivity of the RTP.

Truck Payload

The trucks that carry coal have different carrying capacities. Some trucks can carry up to 40 tons of coal, while others can only carry around 25 tons. The weight bridge reading data distribution chart shows that the mean carrying capacity is around 30 tons (Figure 10). The company's target for truck payload is being met, and there is no issue with the payload.

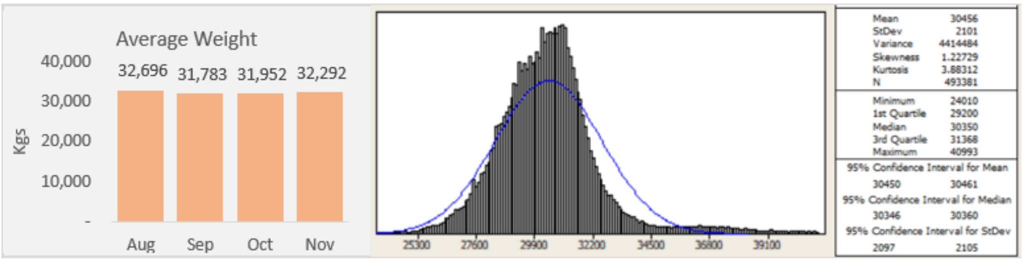

Figure 10. Truck payload Aug – Nov 2022

Effect of Queues:

There is no relationship between queues at PORT and queues at ROM. Several ROMs are used every day, and the trucks regulate themselves along the way to their destinations. The distribution of the data tends to be not Normally distributed with an extreme tail, so Spearman correlation is used to test the correlation between the queues at PORT and ROM. The correlation is calculated every 15 minutes offset, up to 135 minutes, and there is no significant correlation between queues at PORT and ROM at any given time offset.

Table 3. Correlation between Queues at PORT and ROM with Offset

	Offset_min	corr	p_value
0	0.0	-0.039696	1.398741e-06
1	15.0	-0.060379	2.092466e-13
2	30.0	-0.072884	7.514834e-19
3	45.0	-0.082892	6.235240e-24
4	60.0	-0.087140	2.772905e-26
5	75.0	-0.082800	7.038757e-24
6	90.0	-0.070979	5.954387e-18
7	105.0	-0.063669	9.777009e-15
8	120.0	-0.053560	7.478680e-11
9	135.0	-0.043391	1.341614e-07

PORT Capacity and Incoming Hauling Capacity

Trucks regulate themselves before the last segment to PORT (S6) by increasing their speed, overtaking, or slowing down. Therefore, other segments cannot be used to monitor the queue potential in PORT due to the high uncertainty and time needed to reach segment 6 road. The distribution of truck quantity and PORT capacity is not normally distributed, and Spearman correlation is used to measure the correlation. Incoming trucks in S6 are moderately positively correlated with PORT capacity.

	Offset_min	corr	p_value
0	0.0	0.505782	1.135476e-46

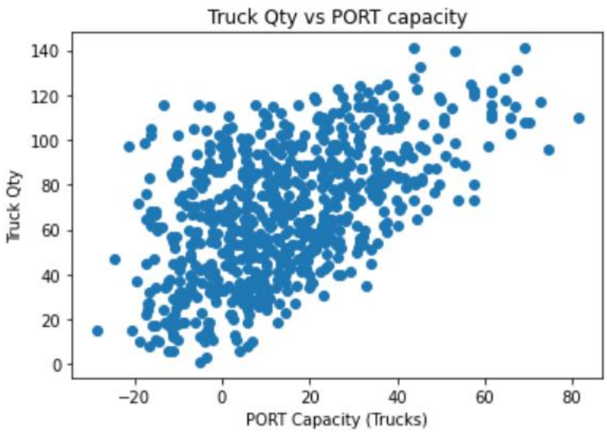

Figure 14 Truck quantity vs PORT capacity

DISCUSSION

Table 4. Root Cause Analysis

*NRC = Not Root Cause, RC = Root Cause

No	Sub	Possible Root Cause	Remark & Summary	Status*
1	Road Activity	Intersection	The intersection has the same effect for all trucks and it's relatively permanent, this is not a root cause for small trucks as bigger trucks have no problems with it.	NRC
2		Road Maintenance	Road maintenance will have the same effect for all trucks, this is not a root cause for small trucks as bigger (DDT) trucks have no problems with it.	NRC
3		Road Surface	This also will have the same effect for all trucks, this is not a root cause for small trucks as bigger trucks have no problems with it.	NRC
4	ROM Activity	High Loading time	Evidence shows that Loading time has relatively stable performance. Some spike occurs but not to the point of reducing productivity significantly.	NRC
5		High Maneuver time	Evidence shows that in ROM, 1.5 or 2 side loading methods are used, there are several anomalies but the impact is balanced by others that have lower maneuver time. This is not a root cause.	NRC

6		Unbalanced Truck movement	When there are obstructions at hauling roads or idles in ROM or PORT for some time, there will be inefficient resource usage. This is a waste and the root cause of the low productivity.	RC
7	ROM Activity	Loading Capacity< Hauling capacity	Queue at ROM rarely happens. High queue (>12 trucks) at ROM happens due to special cause). This is not a root cause	NRC
8		Loader breakdown	Loader is critical and focused in operation. If a loader will be unavailable for a long time, the supervisors will adjust the fleet accordingly. This is also not a major root cause	NRC
9	PORT Activity	High dumping time	By observation, this variable is relatively stable but has some points to be highlighted as improvement potential.	NRC
10		High Maneuver time		
11		Unbalanced Truck movement	The same with item 6	NRC
12		Crushing Capacity< Hauling capacity	There is little capacity to re-route trucks in this activity. Evidence shows that hauling capacity at the nearest segment (S6) has a medium to high correlation with a queue at PORT-B. This is a root cause	RC
13		Loader breakdown	The same with item 8	NRC
14	Road congestion	cut-off road	This will affect all trucks in the cycle. This is not a root cause	NRC
15		Material condition	This is a given condition because the cost to purchase good materials is very expensive and takes a long time. Mine must have a long lifetime to make the purchase feasible.	NRC
16		Material not uniform		NRC
17		Incident	This will only affect all trucks in the cycles. This is not a root cause	NRC
18		Force Majeure	If this happens, this will affect all trucks in the cycles. This is not a root cause	NRC
19	ROM Problems	Low Pit Performance	Pit performances are buffered by stocks in ROM, so if any problems happen with Pit performance, it will have little effect on hauling. This is not a root cause	NRC
20		Weather	This will affect all trucks in the cycle. This is not a root cause	NRC
21		Self-Combustion	This will only increase the delay for one or two loaders, this is not a root cause because the combustion area will be isolated and the loading point will switch accordingly.	NRC

22		Incident	The same with item 17	NRC
23	Low Working Hour Utilization	Weather	This will affect all trucks in the cycle. This is not a root cause	NRC
24		No Driver	This will reduce truck quantity and the trucks will not operate from the beginning if there's no driver. This is not a root cause	NRC
25		Incident	The same with item 17	NRC
26		Demo/Social/Community Problem	If this happens, this will affect all trucks in the cycles. This is not a root cause	NRC
27		Other standby	This will reduce trucks in the cycle and affect truck quantity in the system. This will relate to unbalanced truck movement/cycles.	NRC
28		Breakdown	This will reduce the truck quantity and automatically will be replaced by a transporter. This is not a root cause	NRC
29	Low productivity per hour	Low truck quantity	This will reduce truck quantity, this is not the root cause	NRC
30		Low truck payload	The truck payload was relatively stable and most have considerably good payload. This is not a root cause	NRC
31		High truck cycle time	This item analyzed in item no 1 - 10	NRC
32		Low loader total capacity	The same with item 8	NRC

The cause mapping and root cause identification analysis presented above provide a valuable framework for understanding the factors contributing to the low productivity in the coal hauling system. By identifying two major root causes, namely unbalanced truck movement/cycles and crushing capacity less than hauling capacity, the analysis highlights the areas that require improvement to optimize the system.

A comparison of this analysis with previous research reveals similar root causes for low productivity in mining operations. Studies have shown that unbalanced truck movement is a significant factor affecting productivity. Similarly, a study by Rahman et al. (2020) on a coal mine in Indonesia identified crusher downtime as a major contributor to prolonged truck waiting times.

To address the identified root causes, the strategies proposed above align with established approaches for improving mining productivity. Regular maintenance and repair of equipment, employee training and development, and the implementation of technology have been shown to enhance equipment performance and reduce downtime. Similarly, continuous improvement through regular evaluation and analysis of performance data, as well as collaboration with other companies, has been found to optimize mining operations and improve productivity (Rahman et al., 2020). Furthermore, safety remains a critical aspect of mining operations, with regular safety audits and training programs playing a key role in ensuring compliance and fostering a strong safety culture among employees.

In conclusion, the cause mapping and root cause identification analysis presented above provide valuable insights for improving the efficiency and productivity of the coal hauling system. The strategies proposed, including regular maintenance and repair of equipment, training, and development of employees, implementation of technology, continuous improvement, collaboration with other companies, and a focus on safety, are consistent with prior research and can help PT BORNEO optimize its coal hauling operations and increase profitability.

CONCLUSIONS

Based on the research findings, it can be concluded that several key factors significantly impact the productivity of RTP in PT. BORNEO. The most important factor is the ROM activity (average loading time), which has a direct correlation with productivity. Random stoppages along the shift also have a significant impact on productivity, as they can cause queues and delay the overall system. Additionally, the loaded condition during change shift is an important variable that needs to be addressed to prevent pseudo-traffic jams and increase efficiency. While stoppage before rest time, stoppage in loaded condition, and stoppage at major pray time (*Ashar*) can have some impact on overall productivity, they are not considered priority areas for improvement due to their relatively minor impact. Finally, by optimizing a combination of operational parameters, such as reducing loading time, increasing loaded trucks in change shifts, and allowing for a small percentage of truck stoppage along the shift, it is possible to increase productivity. These findings suggest that targeted improvements to operational variables can significantly increase the efficiency of the RTP system in PT. BORNEO.

LIMITATION & FURTHER RESEARCH

Despite the valuable insights provided by this research, several limitations should be considered. First, the study was conducted only in one company (PT BORNEO), and the findings may not be generalizable to other mining companies because the hauling process in every company is different in terms of road length, longer roads will have higher uncertainty and checkpoint positions. Second, the study on ten operational variables (empty time, loaded time, ROM activity, PORT activity, Queue PORT, Queue ROM, Truck quantity, PORT capacity, ROM capacity, portion of loaded condition at change shift), and there may be other variables that also affect productivity. Third, the study was conducted over a relatively short time, and the results may not be indicative of long-term trends. Finally, the study relied on data provided by the company, and there may be errors or inaccuracies in the data that could affect the findings.

To overcome the limitations of this study, further research could be conducted in several areas. First, the study could be replicated in other mining companies to determine if the findings are consistent across different organizations. Second, additional operational variables could be included in future studies to provide a more comprehensive analysis of the factors that affect productivity. Third, future research could be conducted over a longer period to determine if the results are stable over time. In conclusion, forthcoming research endeavors could employ various data sources to corroborate the results and mitigate the prospective influence of errors or inaccuracies in the data. Furthermore, the utilization of machine learning techniques could be explored for predicting queues and hauling performance.

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