Productivity Improvement of Coal Barge Loading Conveyor using Lean Techniques: A Case Study in Coal Mining Company

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Abstract

Lean manufacturing is a management approach focused on operational improvements. Lean concepts are being utilized by industries to improve the performance of current processes. The purpose of this paper is to uncover the significance of lean manufacturing concept implementation in the mining industry, especially in coal barge loading conveyors. Bottleneck analysis, process standardization, and process balancing has been utilized to improve the coal barge loading conveyor facility. Results indicated the productivity of the barge loading conveyor improved 161% from 372 to 971 tons per hour by implementing the lean principle. Productivity improves significantly after implementing lean manufacturing techniques in a case company. This article demonstrates the practical application of the lean technique in coal barge loading conveyors showing how it can bring real breakthroughs in productivity improvement in the coal mining sector.

Keywords
Productivity, Lean, Improvement, Mining, Conveyor

1. Introduction
Productivity is defined as a ratio between the output volume and the input volume. In other words, it measures how efficiently production inputs, such as labor and capital, are being used to produce a given level of output (Kulkarni et al. 2014). Production is concerned with an increment of output over a given period; productivity is concerned with more output and less time consumed. Considering the high demand for the product in a short of given time has pushed the production team to think of a way to improve productivity. One way to improve productivity is by implementing lean manufacturing. The concept of lean manufacturing originated in the automotive industry and is widespread in the manufacturing industries. The lean concept has often been successfully implemented in companies to achieve considerable savings in production by improving the efficiency and productivity of the production process (Manikandaprabu & Anbuudayasankar 2019). The lean objective is to minimize waste and to add more value to the existing process so that the system performance gets improved significantly. Lean manufacturing tools and techniques mainly focus on reducing waste within the process which will reduce the process lead time, improve productivity, and also the product quality.

To improve efficiency and productivity lean concept has been implemented in various manufacturing industries (Duran et al. 2015), (Rangrej et al. 2015), (Zaidi et al. 2021), (Edwin et al. 2020). However, its application in the mining sector is still little studied. The purpose of this study is to increase the productivity of coal Barge Loading Conveyor (BLC) using the lean concept. Implementing the lean concept in the mining environment are very challenging since the lean concept originated from manufacturing where the environment in manufacturing is controllable. However, the mining operation is different, characterized by an uncertain, dynamic, volatile, and risky work environment (Wijaya et al. 2009).

In the automotive industry, production and assembly take place in relatively small areas, with little variation between companies. Therefore, customization of the implementation of lean methods in one of them is usually the same as in other companies. However, mines are very large and wide areas. In some cases, the development takes place over hundreds of square kilometers. The fact that large-scale production cannot be planned also makes material requirements planning difficult (Helman 2012). Those differences bring a consequence on the dissimilarity of values, needs, and characteristics that if not deliberate and carefully lead to potential pitfalls.

Considering the rapid increase in coal demand, mining industries need to increase their potential in production & effectiveness to fulfill the delivery time and demand. The production facility should be prepared with the capacity and have to decrease costs at the same time. This paper discusses the case study in applying the lean principle to the mining industry, especially in improving the productivity of coal barge loading conveyor facilities. The case study is located in one coal mine in Indonesia. The existing BLC capacity under this study has low productivity, only achieving 372 TPH while the company target was 800 TPH. This situation has impacted on the company's barging performance and coal delivery schedule, thus making low financial performance. This situation encourages the management team to decide to implement the lean concept to improve the productivity of its coal barging operation.

2. Literature Review

In industrial processes, lean manufacturing is widely known for eliminating non-value-added activities, integrating people into production facilities, and striving for continuous improvement (Zaidi et al. 2021). The underlined lean manufacturing concept is to produce products without waste. There are seven types of waste: transportation, inventory, excess production, motion, waiting, extra processing, and defective product waste. Lean manufacturing systems have various techniques to improve productivity. In a lean manufacturing environment, the primary focus is on eliminating waste of all kinds, including space, time, energy, motion, materials, inventory, and defects (Kulkarni et al. 2014), (Dave and Sohani 2019).

Numerous studies conducted by researchers confirm that implementing lean practices in companies and organizations improves organizational performance in all aspects, including quality, delivery, safety, and overall company profits (Dave and Sohani 2019), (Karim and Arif 2013), (Jignesh et al. 2019), (Gazoli and da Rocha 2019). Lean manufacturing provides a variety of tools and techniques to effectively address and identify different types of waste and improve efficiency in different situations (Wong and Wong 2015). The most commonly used tools and techniques are 5S, Kaizen, Standardized Work, Plan-Do-Check-Act (PDCA), 5 whys, set up reduction, visual management, Just-In-Time (JIT), Total Production Maintenance (TPM) and Value Stream Mapping (VSM).

2.1 Applying the Lean Principle to Mining Industry

The starting point for applying lean principles is understanding value based on customer needs. In the coal mining industry, products and customers all have their characteristics. Coal mining products are by nature standard products with well-defined specifications and requirements. Quality and price are determined by the market. Standardization is a key foundation of lean, requires rigorous work to implement, and applies to all other lean tools. In the mining industry, standardization is a difficult task as mining jobs are highly dependent on uncontrollable factors such as environmental conditions (Wijaya et al. 2009). The article on lean implementation in mining mentioned that many of the tools claim to be incompatible with the mining industry context. The results suggest that the form and extent of lean production in mining differs from other industries due to the characteristics of the industry itself (Lööw 2019). The variation in work from time to time is high and different conditions require different ways of working (Loow 2015). However, mining allows for some degree of standardization. The non-added value that exists in the mining industry is described as follows: waiting, overproduction, rework, motion, over processing, and inventory.

2.2 Case Study Context

The case study was conducted in one coal mining project in Indonesia that utilize BLC to transfer coal from the stockpile to the barge for shipment. BLC consists of belt conveyor systems are the key equipment for the continuous transport of large quantities of bulk coal from the stockpile to the barge. Process barging consists of several processes, coal is located at the port stockpile, then loaded into the truck using wheel loaders or excavators, and the trucks transport the coal to BLC. The main components of BLC are the hopper, transfer conveyor, and main conveyor. The truck dumps the coal into the hopper and then continuously transfers the coal into the barge using a conveyor system. The barging process is described in Figure 1. The distance from the stockpile to the BLC hopper varies between 250-1000 meters, depending on the stockpile location. During the barging process, several trucks and loading equipment were assigned to perform the loading. In this case study distance between the coal stockpile and the BLC location is between 250-1000 meters.

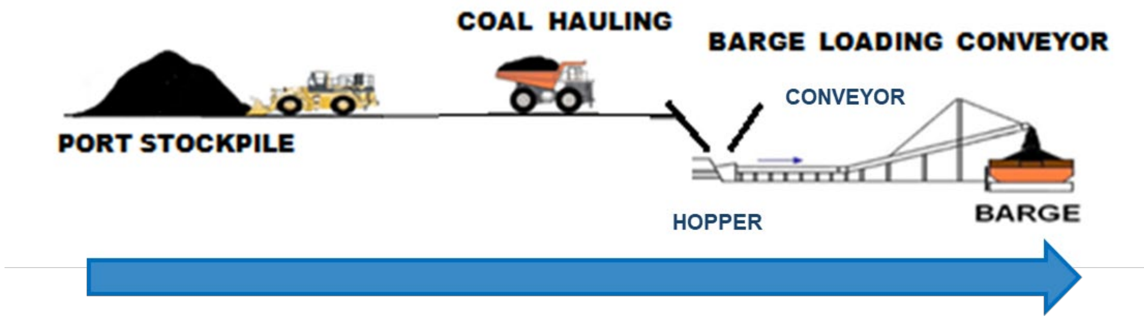

Figure 1. Barging Flow Process

2.2 Barge Loading Conveyor

Belt conveyor systems are the key equipment for the continuous transport of large quantities of materials in many industries. A typical belt conveyor system consists of endless belts for traction and bearing components, driven by redundant heavy-duty electric pulleys (Zeng et al., 2020). In general, a belt conveyor is a continuous conveying machine that consists of a conveyor belt and a bearing mechanism. With the advantages of long distance, high speed, and large capacity, belt conveyor systems are used widely (Zeng et al., 2020).

2.4 Barging Productivity

Barge loading conveyors are equipment facilities for transferring coal from storage piles to barges. The load capacity of the conveyor is determined by the size of the dynamo that rotates the rubber conveyor. The loading capacity of the conveyor determines the speed at which coal is loaded onto the barge. A high loading rate reduces loading time and saves time proportionately. The higher the capacity the higher the productivity. BLC productivity is measured by the ratio of total coal tonnage being transferred with total working time called ton per hour (TPH) which describe in Equation 1.

$$Productivity\ (TPH) = \frac{Total\ tonnage\ (metric\ ton)}{Working\ time\ (h)} \quad (1)$$

3. Methodology

The method used in this study case consists of five steps as described in Figure 2. Step 1: Identify the problem, during this phase we discussed with the management team to identify what is critical to their process. Based on the discussion we identify that the company has a problem with its coal barging volume and delivery. The main problem as the company described that barging volume is very essential to meet delivery demand and monthly barging target. However, the monthly barging volume achievement is always below the target. Step 2: Data collection, data before improvement have been collected from the field observation. Step 3: Data analysis, we use excel to analyze the data. Step 4: Improvement proposal, by Appling appropriate lean tools to improve productivity. Step 5: result and discussion, we collect data after improvement and compare BLC productivity before and after improvement.

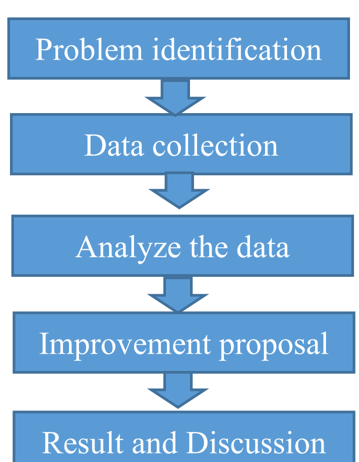

Figure 2. Research Method

3.1 Problem Identification

To identify the problem the first step is to break down the barging process into a detailed sub-process, which enables the analysis of the performance of each sub-process as described in Figure 3. Loading is the process of loading coal onto a truck using loading equipment utilizing an excavator and wheel loader. Hauling utilize truck with a capacity of 22 metric tons.

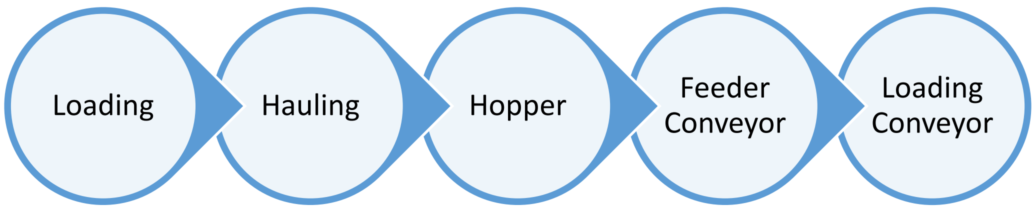

Figure 3. Barging Sub Process

3.2 Data Collection

Data collection is divided into three scenarios based on the hopper gate opening position. Since the BLC system has a hopper between process hauling and conveyor. The Hopper infeed coal from the truck and transfer it to the conveyor which is located under the hopper itself. This hopper has a gate that can open and close manually in three opening positions: 30 cm, 40 cm, and 50 cm. This opening position will impact the speed of coal flow to the conveyor, the wider the opening position the more coal transferred to the conveyor. Coal stockpile distance also varies from 250 meters to 500 meters which will impact hauling cycle time variation. In this study, we collect data by observing the capacity of each su- process. Trials has been performed to verify the capacity of each sub-process by collecting loading tonnage and cycle time the convert to ton per hour. Obtained data is described in Table 1.

Table 1. Loading Capacity for 250 Meters Distance

Process	**Gate 30 cm**	**Gate 40 cm**		**Gate 50 cm**
Loader	450	450		450
Hauler	372	372		372
Hopper	500	770		1080
Transfer Conveyor	1100	1100		1100
Main Conveyor	1090	1090		1090

Based on data in Table 1 the capacity of the hopper capacity increases when the hopper gate opening position increase. The gate opening position at 30 cm has a capacity of 500 TPH, the gate open at 40 cm has a capacity of 770 TPH and the opening position at 50 cm has a capacity of 1080 TPH. It implies that capacity is affected by gate position, which means when the gate opens widely more coal will go through the gate thus increasing the hopper capacity. Based on data in Table 1, the bottleneck of the system is hauler 372 TPH.

3.3. Data Analysis

Based on available data the BLC design capacity should be able to achieve 1000 TPH. However, based on existing data collected from the operation the productivity was 372 TPH on average. The first step is to break down the BLC system into detailed components. To achieve 800 TPH, then all the BLC systems: loaders, haulers, hopper, feeder conveyors, main conveyor, or loading conveyor must achieve a minimum of 800 TPH as visualized in Figure 4. Otherwise, if one of the components is below 800 TPH then it will be considered a bottleneck, and the lowest capacity of the system will dictate the whole capacity of the BLC system. To improve and maintain the productivity performance of the BLC the bottleneck must be improved.

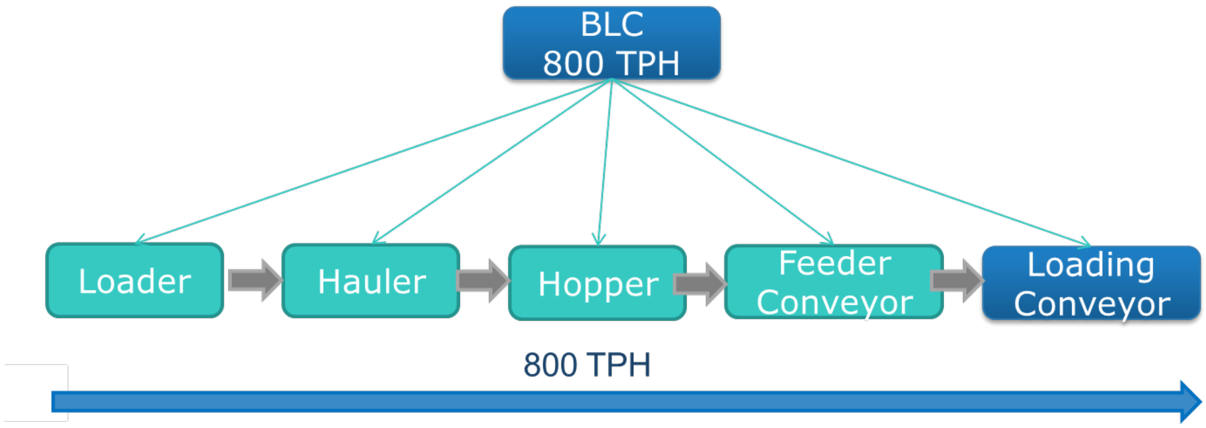

Figure 4. Ideal Capacity of BLC System

Observation and time study was performed to analyze the data in more detail. Each process within the BLC system was studied to check the capacity of each process; loader, hauler, hopper, feeder conveyor, and loading conveyor. Several tests have been conducted in the field and data were collected for further analysis. Data collection was designed and we collect data on coal loading capacity from a stockpile 250 meters from BLC. The main consideration to select 250 meters is because fewer trucks are required and also considering the visibility when assigning a person to collect the data. He must be able to see the truck's movement. The BLC hopper has a gate mechanism that can be opened with three alternatives: 30, 40, and 50 centimeters, where the BLC operator can adjust the gate with a special handle.

After several trials with 250 hauling distance and using hopper gate opening position 30-, 40- and 50-centimeters option, we found data as described in Figure 5. The result from three trial scenarios indicated that the feeder conveyor and loading conveyor can achieve 1050 TPH. However, the capacity of the hopper is defined by the gate opening position. Data indicated that hopper gate opening positions 30, 40, and 50 cm capacity are 500, 770, and 1080 TPH respectively. From Figure 5 it can be seen that the lowest capacity was hauler 372 TPH and followed by loader 450 TPH. This indicated that the hauler and loader are the bottlenecks since it was the lowest capacity within the system and dictated the whole system capacity.

The data conclude that the productivity of the hauler and loader below target needs further investigation. After a deep investigation into truck hauling and loading equipment, there are several root causes. They are: no standard cycle time from the stockpile to BLC and leading to there being no standard truck number for each stockpile designation. The number of trucks for 500 meters distance should be more than 250 meters since the cycle time is higher. After several field investigations, we found some problems that affected the loading and hauling cycle time. Road conditions and bad traffic arrangements have caused irregular truck motion and cycle time variation. During the coal loading process into the truck, there is no standard loading position or loading maneuver that causes the loading cycle time much higher than expected. To meet the delivery demand company sets the BLC target to 800 TPH. To achieve this target, the process should be analyzed in detail and process analysis should be carried out. To achieve 800 TPH all BLC systems should be able to achieve a minimum of 800 TPH.

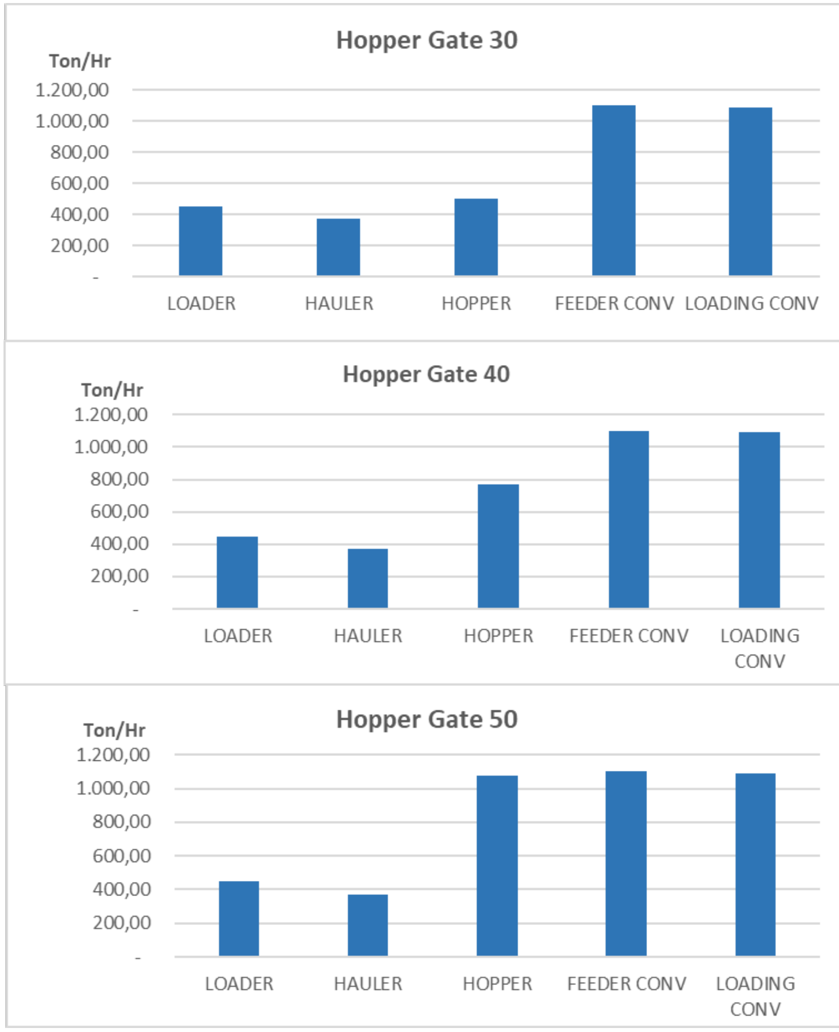

Figure 5. Graph of Barging Sub-Process Capacity

3.3 Problem Identification

Based on data described in Figure 5, enables us to analyze the capacity of each sub process. The data indicated that the feeder conveyor and main conveyor have a capacity of 1100 TPH and 1090 TPH respectively, they were above 800 TPH. It indicated that there is no capacity problem on the feeder and the main conveyor. The next step is hopper capacity verification, after conducting a trial and data collection when the gate open position was 30 cm, it was able to feed 510 TPH, when open at 40 cm it was able to feed 770 TPH, and when open at 50 cm able to feed 1080 TPH. This indicated that the hopper capacity able to perform above 800 TPH when the hopper gate open 50 cm. Based on the data above it can be seen that the real problem was located at the loading and hauling capacity under 800 TPH. This data lead to further investigation which focuses on the loading dan hauling process. To achieve a hauling capacity of 800 TPH, the trip-per-hour target should be 40 trips per hour. However, based on daily observation data hauling performance only achieve about 17 trips per hour as shown in Figure 6. Based on this data 17 trips per hour with a truck capacity of 22 MT and a total hauling capacity of only 372 TPH

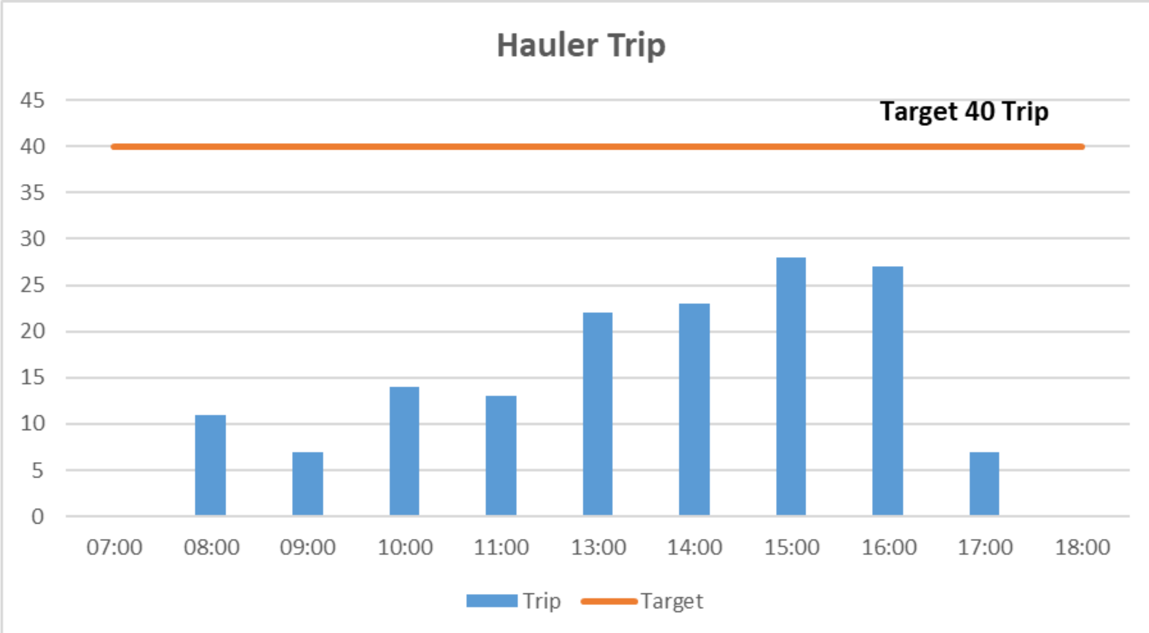

Figure 6. Hauler trip performance

The team conducted observation to find abnormalities during the hauling process. The abnormality found during observation impact hauling productivity described in Table 2.

Table 2. Problem Identification Based on Field Observation

No	Finding
1	Bad road condition/Muddy Road
2	Lack of traffic management
3	No standard for loading position
4	No standard for queue system
5	No standard for dumping position
6	Mismatch number of hauler and loader

3.4 Improvement Proposal

To improve the capacity, several initiatives have been proposed and conducted as described in Table 3. Improvement focuses on how to improve the capacity of hauling.

Table 3. Improvement Proposal

No	Finding	Improvement
1	Bad road condition/Muddy Road	Drainage system & road maintenance
2	Lack of traffic management	Visual management (Figure 7a)
3	No standard for loading position	Standardized loading maneuver (Figure 7b)
4	No standard for queue system	Standardized queuing system (Figure 8)
5	No standard for dumping position	Standardized dumping maneuver (Figure 9)
6	Mismatch number of hauler and loader	Standardized hauler and loader (Table 4)

To speed up the hauling cycle time visual traffic management in Figure 7a and standard truck maneuver at the loading point in Figure 7b have been made. Traffic management has also been improved, one way in and one way out where in-out truck to hopper has its way as described in figure 7a. It made traffic safer, with one way in and one way out will prevent truck coalition and increase cycle time at the same time. To improve road conditions, we improve the drainage system and perform regular road maintenance.

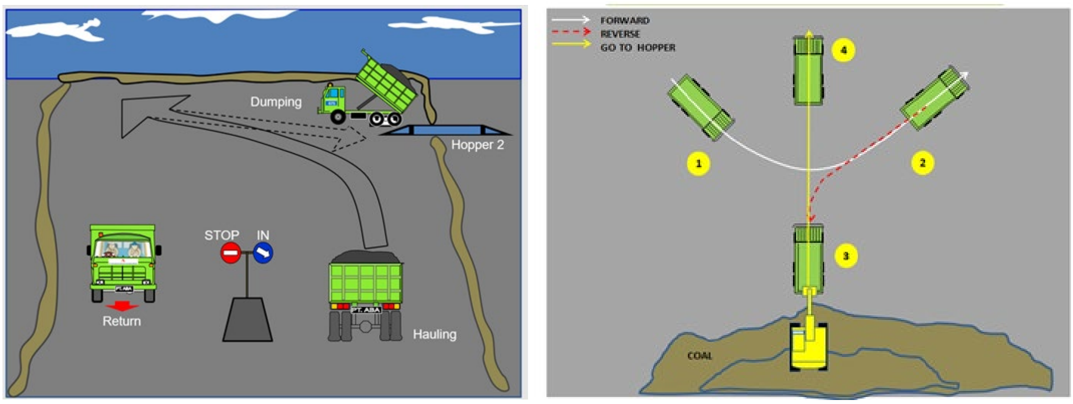

Figure 7a. Visual Management in-out truck to BLC, 7b. Standard truck maneuver at loading point.

To improve the hauling process cycle time some standard related to the truck queue at the loading point and dumping point has been proposed as described in Figure 8, it improves loading cycle time. The next truck must be ready at the queue line right after the previews truck leaves the loading point, it prevents waiting time for the loader.

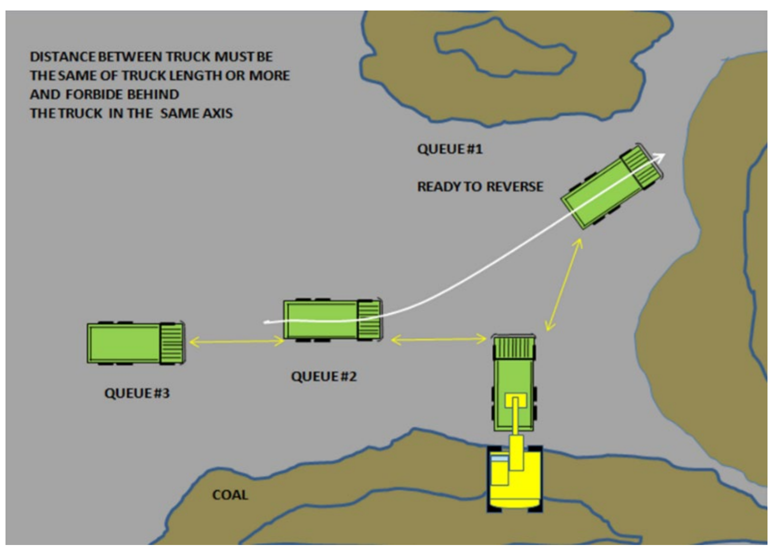

Figure 8. Standard Truck Queue at Loading Point

Standard truck maneuver at the dumping area has been established to improve cycle time at the dumping point. The standard show how the truck maneuver in front of the hopper, which consists of four steps as described in Figure 9.

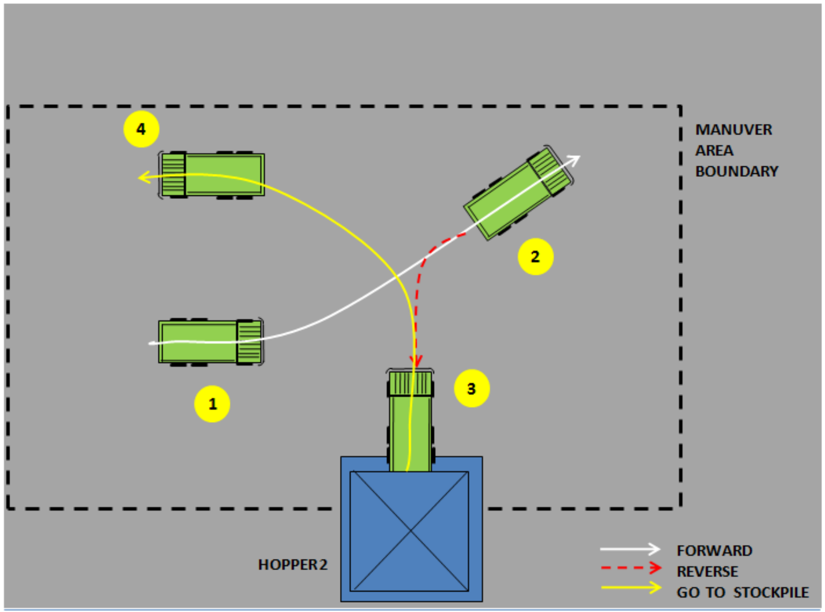

Figure 9. Standard Truck Maneuver at Dumping Area

To improve hauling capacity, we make the standard for hauler versus loader number as described in Table 4. This standard is used as guidance for the operation team to prepare tuck and loading equipment based on stockpile distance. To obtain a loading capacity of 1080, the hopper gate must be open 50 cm.

Table 4. Standard table for Hauler versus Loader Number

Distance (Meter)	Hopper Gate Opening (Cm)	Loader (unit)	Hauler (Unit)
200-300	50	2	4
400-500	50	2	5
500-600	50	2	6
600-700	50	2	7
700-800	50	2	8
800-1000	50	2	10

4. Result & Discussion

After implementing the improvement and using the table standard in Table 4, data were collected again and the result is described in Figure 10. The average trip increases significantly, the average trip achieving 44 trips per hour after improvement. Compare to performance before improvement only 17 trips per hour on average, the increment was 159%. The maximum trip during the observation was 50 trips and a minimum of 40 trips. The BLC capacity achieves 971 TPH on average. The BCL capacity improvement about 161%. This improvement happened since the number of trucks and loaders has been standardized to meet BLC capacity and some operational standardization related to loading, hauling and dumping processes..

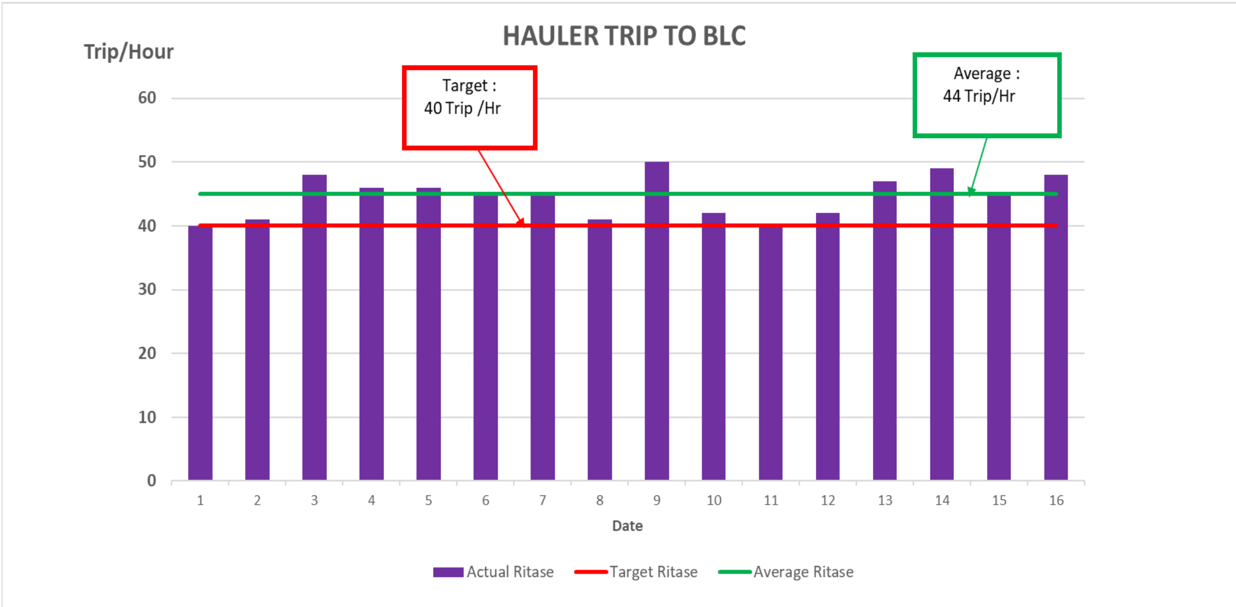

Figure 10. Actual Trip after Improvement

Since the bottleneck has been improved, it impacted the total BLC system capacity. The output from BLC has been measured with Equation 1. The productivity result is described in Figure 11. The average productivity achieves 971 TPH. Compare to the target of 800 TPH the achievement has surpassed the target. The BLC maximum capacity during the observation was 1303 TPH and the minimum was 823 TPH.

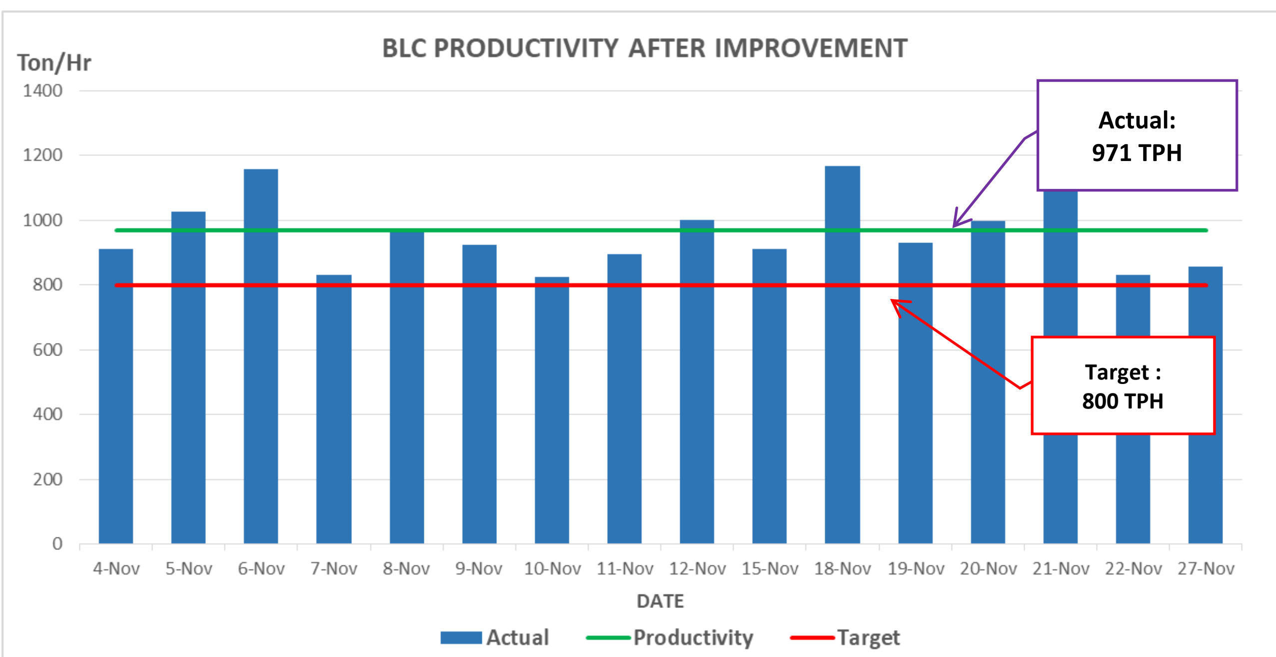

Figure 11. Actual BLC Productivity

If we compare the situation before the improvement the BLC productivity is only 372 TPH on average, after improvement the capacity improved becomes 971 TPH. There was 161% improvement. The improvement contribution came from the hauler and loader standard matching factor as described in Table 4, and process standardization that reduced hauling cycle time. Hauler and loader standard unit numbers are very significant to increase hauling productivity and increasing the hauling trip per hour, thus impacted to total BLC capacity.

5. Conclusions and Future Research

This study has shown how the lean principle is applied in a non-manufacturing environment. Defining bottleneck, eliminating waste, process balancing, and process standardization has improved BLC system capacity. Balancing the capacity of the hauler and loader has improved the total trip and total BLC system capacity, it enables the company to increase barging volume to meet delivery demand. Besides that, it shows us the implication of the study to the practical contribution that evaluating BCL capacity must consider the coal intake as a total system. Further study needs to be performed to evaluate the truck hauling cycle time variation and the total trip per hour. Combining lean and digitalization to reduce waste and improve productivity of BLC system need to be tested in real operation.

References

Dave, Y., & Sohani, N., Improving productivity through lean practices in central India-based manufacturing industries. *International Journal of Lean Six Sigma*, vol. 10, no. 2, pp. 601–621, 2019.

Duran, C., Cetindere, A., & Aksu, Y. E., Productivity Improvement by Work and Time Study Technique for Earth Energy-glass Manufacturing Company. *Procedia Economics and Finance*, vol. 26, no. 15, pp. 109–113, 2015.

Edwin Joseph, R., Kanya, N., Bhaskar, K., Francis Xavier, J., Sendilvelan, S., Prabhahar, M., Kanimozhi, N., & Geetha, S. , Analysis on productivity improvement, using lean manufacturing concept. *Materials Today: Proceedings*, vol. 45, pp. 7176–7182, 2020

Gazoli de Oliveira, A. L., & da Rocha Junior, W. R. Productivity improvement through the implementation of lean manufacturing in a medium-sized furniture industry: A case study. *South African Journal of Industrial Engineering*, vol. 30, no. 4, pp. 172–188, 2019

Helman, J. Analysis of the potentials of adapting elements of Lean Methodology to the unstable conditions in the mining industry. *AGH Journal of Mining and Geoengineering*, vol. 36, pp. 151–157, 2012.

Jignesh, J., Bhupesh, G., & Tejas, V. Review of Productivity Improvement in Pressure Vessel Manufacturing Industry. *Revista de Tecnologías Emergentes e Investigación Innovadora*, vol. *6,* no. 5, pp. 430–435, 2019.

Karim, A., & Arif-Uz-Zaman, K. A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations. *Business Process Management Journal*, vol. 19, no. 1, pp. 169–196, 2013.

Kulkarni, P. P., Kshire, S. S., & Chandratre, K. V. , Productivity Improvement Through Lean Deployment & Work Study Methods. *International Journal of Research in Engineering and Technology*, vol. 03, no. 02, pp. 429–434, 2014.

Loow, J. Lean production in mining: An overview of Lean Production in the mining industry, *Luleå University of Technolog*y, 2015

Lööw, J. An investigation into lean production practice in mining. *International Journal of Lean Six Sigma*, vol. *10,* no. 1, pp. 123–142, 2019.

Manikandaprabu, S., & Anbuudayasankar, S. P. , Productivity improvement through lean manufacturing. *International Journal of Engineering and Advanced Technology*, vol. *8, no.* 5, pp. 2657–2660, 2019.

Rangrej, S., Samvatsar, K., Chauhan, P., & Sheth, S. Application of Lean Manufacturing Principles for Process Time Reduction-A Case of Conveyor Pulley Manufacturing, *5th National Conference on "Recent Advances in Manufacturing (RAM-2015)*", 15-17 May, 2015

Wijaya, A., Kumar, R., & Kumar, U., Implementing lean principle into mining industry issues and challenges. *International Symposium on Mine Planning and Equipment Selection*, pp. 1–9, 2009.

Wong, Y. C., & Wong, K. Y. Approaches and practices of lean manufacturing : The case of electrical and electronics companies, *Global Journal of Business Management*, vol. 9, no. 7, pp. 1–12, 2015.

Zaidi, I. H., Khan, M. A., Bukhsh, M., Yaseen, R., & Shaikh, S. A. , Implementation of lean manufacturing practices in diverse manufacturing industries. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 7255–7266, 2021.

Zeng, F., Yan, C., Wu, Q., & Wang, T., Dynamic behaviour of a conveyor belt considering non-uniform bulk material distribution for speed control. *Applied Sciences (Switzerland)*, vol. 10, no. 13, 2020.

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