p–ISSN: 2723 – 6609 e-ISSN: 2745-5254
Vol. 6, No. 1, January 2025 http://jist.publikasiindonesia.id/

Increasing Coal Crushing Production at PT. XYZ Using Lean Six Sigma Approach

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Keywords: coal crushing, lean Six Sigma DMAIC, operational efficiency, production enhancement, operational management.

ABSTRACT

Coal is a primary energy source in Indonesia, particularly for steam power plants (PLTU). The coal crushing process at PT. XYZ is a critical stage in coal mining operations; however, the company faces operational challenges that hinder the achievement of production targets. This study aims to identify the main issues, analyze factors affecting productivity, and design effective improvement solutions. The methodology used is DMAIC (Define, Measure, Analyze, Improve, Control). In the Define phase, process mapping and waste identification were conducted. The Measure phase utilized a Pareto diagram to determine key issues. Root cause analysis using the 5 Why's method was performed in the Analyze phase. In the Improve phase, solutions were designed through Future State Mapping, while in the Control phase a Kanban Board for monitoring. The results show that Year-to-Date coal crushing production as of October 2024 reached 9.9 million MT, or 94% of the 10.56 million MT target, representing a 139% increase compared to October 2023, which only reached 7.2 million MT.

Introduction

Coal is an important energy source in the world, especially in the industrial and power generation sectors. (Djordjevic & Čečević, 2015). Coal-fired power plants tend to be an affordable option and play an important role in power generation for decades to come. (Mousazadeh et al., 2024).

Coal mining activities have one important part of the process, namely Coal Crushing which is the process of breaking coal into small pieces according to the size desired by consumers, facilitating delivery, storage, and use in various industrial facilities. (Ahila & Battacharya, 2018).

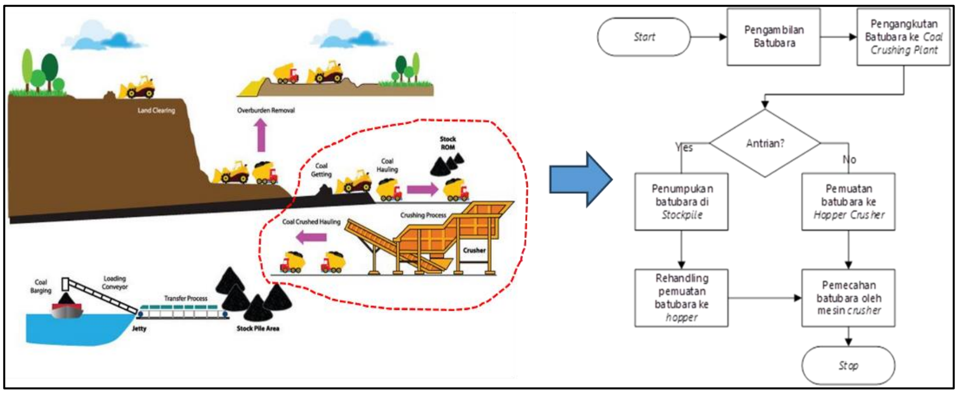

Figure 1 Coal Crushing Process of PT. XYZ (Overview PT. XYZ, 2023)

In Figure 1, the coal crushing process at PT. XYZ begins with the extraction of coal from the mining area (Lisiecki et al., 2023). The coal is then transported by truck to the coal-crushing plant. If there is no queue, the coal is directly loaded into the hopper (crusher machine shelter) to be further broken by the crusher machine into coal products of the desired size. However, if there is a queue, the coal is first stacked in the stockpile area (temporary stockpiling place) before being loaded back into the hopper for further cracking by the crusher machine. (Castillo et al., 2015). Here it can be seen that the main activity in coal crushing is loading coal into a stockpile or into a hopper involving a truck as a means of transporting and breaking coal by a crusher machine. (Damij & Damij, 2021).

In its operations, every year PT. XYZ has a coal-crushing production target set in the Key Performance Indicator (KPI). However, in its implementation, there are often obstacles and obstacles so that the actual production results are not by the target which causes a decrease in total coal-crushing production. (Sumasto et al., 2023).

In the Define phase, the process of identifying all data will be carried out, then SIPOC (Supplier, Input, Process, Output, Customer) mapping will be carried out, VOC (Voice Of Customer) identification and the Current State Mapping process will be carried out on the ongoing process. (Hess & Benjamin, 2015). In this Measure phase, the author determines the main problems that occur with the Pareto diagram to the causes that often arise which are then identified and given priority to be addressed first. Furthermore, in the Analyze phase, the author analyzes the determination of the root cause of the main problem with Root Cause Analysis (RCA) with the five whys method so that the necessary steps can be determined so that the main problem can be eliminated or not repeated. In the Improve phase, Future Value Mapping will be formulated and in the process of executing the implementation of improvements, the researcher uses the Kanban Board Microsoft Planner to visualize tasks or work that will be carried out, in the process, or have been completed in a stage of the process. (Wu et al., 2024). Next is the last phase of control where the researcher ensures that the improvements that have been made remain sustainable and provide consistent results by the set KPIs. It is hoped that this improvement process can increase coal-crushing production from the planned target. (RIZZONI, 2023).

Based on the background described above, the problem faced is how to increase coal-crushing production by maximizing productivity through the application of the Lean Six Sigma DMAIC approach. (Vargas et al., 2024).

This study aims to identify the main waste and variations in the coal crushing process to determine the factors that most affect production unachievement, analyze the main causes of waste and variations to find the right solution, and design effective remediation based on root cause analysis. In addition, this study also aims to implement improvement solutions with risk analysis-based strategies to increase coal crushing production, as well as evaluate and control the implementation of improvements to assess their success and ensure the sustainability of the improvements made.

Method

There are two data needed in this study, namely quantitative data, and also qualitative data. This data will be processed later, with selected methods to solve existing problems.

Quantitative Data

The quantitative data needed in this study includes KPI (Key Performance Indicator) data as follows:

1. Coal crushing production data which contains data on coal crushing achievements on a daily, monthly, and annual basis.
2. Productivity data of each crusher machine which contains data on the ratio between the output produced and the inputs used in the coal-crushing production process
3. Crusher Performance data which contains numerical information related to the performance of the crusher machine includes the throughput or number of tons of coal crushed per unit of time with the following calculation formula:

$$Performance\ Rate = \frac{Actual\ Production\ Capacity}{Ideal\ Run\ Time}\ x\ 100\% \qquad (3.1)$$

Information:

1. Actual production capacity is produced from total production divided by operating time.
2. Ideal run time is the ideal capacity of the machine in producing products.
3. Cycle Time Truck data is data that contains the recording of the time it takes for the truck to complete one cycle of transporting coal from the loading area to the crusher and back again. The cycle includes waiting time, transportation time, queue time, unloading time, and return travel time, all of which are expressed in units of time.
4. Standby Parameter data is operational, standby, and idle variable data that has been agreed upon by PT. XYZ records its operational activities such as data waiting for materials, empty hoppers, blocking crushers, rain, dust, customer problems, and social issues.

5. Crusher Availability data reflects how often the crusher is available and can operate under normal conditions over some time with the following formula:

$$Availability\ Rate\ \frac{Planned\ Production\ Time - Total\ Down\ Time}{Planned\ Production\ time}\ x\ 100\% \quad (3.2)$$

Information:

1. Planned production time is the total time that machines are expected to work to produce products.
2. Total downtime is the total time during which the machine experienced a sudden breakdown unwanted malfunction or engine adjustment.

Results and Discussion

KPI (Key Performance Indicator)

KPI (Key Performance Indicators) data is used to measure and assess the performance of the coal-crushing process against the goals that have been set within a certain time. This coal-crushing KPI data can serve as a baseline (reference point) because it provides an initial value or performance standard that can be used to compare future performance. This baseline is important to determine whether a goal has been achieved and helps in data-driven decision-making. The following is data on the achievement of coal-crushing KPI at PT. XYZ for 1 year in 2023:

Table 1
Achievement KPI Coal Crushing 2023 PT. XYZ

Items	Plan 2023	Actual 2023	Variance	Achievement
PA (%)	85%	87%	2%	102%
UA (%)	70%	56%	-14%	80%
Productivity (Tph)	2.160	1.848	-312	86%
EWH (Hours)	13,25	12,6	-0,65	95%
Production (Metric Tons)	10.304.380	8.383.792	-1.920.588	81%
OEE	90%	73,68%	-15,57%	83%

Table 1 above shows that although the physical availability of equipment (PA) is better than planned, tool utilization (UA) and productivity have experienced a significant decline. The decline in productivity and effective working hour hours (EWH) had a direct impact on the decrease in total production output by 19%. This can indicate inefficiencies in tool usage and operating time, which need to be further evaluated to understand the root cause, such as potential downtime, technical glitches, or operational management issues. The 102% achievement in PA indicates that the equipment is sufficiently available, but not utilized to its full potential, as reflected in the low achievement of UA and productivity. This situation in the end only resulted in coal crushing production of

8.3 million MT from the target of 10.3 million MT so there was a shortfall in production of 1.9 million MT. For this reason, it is necessary to take corrective action on the non-achievement of each KPI parameter.

SIPOC

SIPOC is used to provide a comprehensive overview of how a process works from start to finish, including the parties involved, the inputs required, the process steps, the outputs produced, and who receives the outputs.

The following is a SIPOC identification table (Supplier, Input, Process, Output, Customer) in the coal crushing process which is collected from stakeholders involved in the business process running at PT. XYZ.

Table 1
SIPOC Coal Crushing Activities at PT. XYZ

Supplier	Input	Process	Output	Customer
TSE (*Technical Service Engineering*) Team	Target *Marketing*	Production Planning according to resources	*Coal Crushing Production Plan*	CCP (*Coal Crushing Plant*) Production Team
Mine (*Pit*)	Raw *coal*	Coal transportation	*Transport cycle time* by standards	CCP (*Coal Crushing Plant*) Production Team
Transport Operator	Transport trucks	Reception in *the hopper*	*Transport cycle time* by standards	CCP (*Coal Crushing Plant*) Production Team
Dumping Man	Transport trucks	Receipt at the *stockpile* if the queue time exceeds the standard	FIFO (*First In First Out*) and *stockpile* setting as standard	CCP (*Coal Crushing Plant*) Production Team
Operator Crusher	*Crusher* (crushing machine)	Coal *Crushing*	The productivity of *the crusher machine* is by the	Hauling *Team* (Coal transportation from CCP to *Port*)
Maintenance Team	*Crusher* (crushing machine)	Coal *Crushing*	Availability of *Crusher* machines as planned	CCP (*Coal Crushing Plant*) Production Team

In Table 2, it can be explained that the SIPOC (Supplier, Input, Process, Output, Customer) model referred to in the table focuses on the coal production process at the Coal Crushing Plant (CCP).

Voice Of Customer (VOC)

The goal of VOC is to gain deep insight into what customers really want and use that information to improve *coal crushing*.

Table 3
Voice Of Customer Stakeholders of Coal Crushing Activities

Team	Necessity	Hope	Voice of the Customer	Improvement Priorities
CCP Production Team	Coal crushing production according to the production plan	Production target achieved	"We need a realistic production plan according to the available resources."	Improved production planning
	Wanting optimal crusher machine productivity	The operation of the crusher machine can be productive according to its capacity.	"We hope the coal crushing time is by the planned capacity."	Optimization of the use of crusher machines
Hauling Team	Requires crushed coal that is ready to be transported on time	Expect standard transport cycle time	"We need coal that is ready to be transported on time without delay."	Accelerating coal readiness
			"We expect the cycle time from crushing to loading to be up to standard."	Improving cycle time standards
Maintenance Team	Ensure the optimal functioning of the crusher and conveyor machine	Provides maintenance to keep the machine running on schedule without downtime	"We need the availability of crusher machines according to the plan without interruption."	Improves preventive care
			"Machine maintenance must be on schedule so as not to interfere with production capacity."	Improved maintenance schedule compliance

Operator Crusher	Want the optimal crusher tool	The machine can crush coal according to the capacity	"We need tools that work optimally so that the destruction goes smoothly."	Improved performance of crusher tools
			"Any technical glitch reduces our daily productivity."	Downtime management improvements
Carrier & Dumping Man	Requires availability of raw coal in the crusher area	There are no delays in the process of transportin g and receiving coal	"We want the raw coal to be transported to the crusher on time without waiting."	Improve transportation accuracy
			"If there are long queues in the stockpile, it slows down the production process."	Better setup in stockpile

Based on Table 3 presented, here are some important analyses that can be taken:

1. Realistic production planning

   The CCP Production Team felt that they were quite satisfied with the existing production plan. However, improvements are still needed to ensure a more realistic production plan, so that it always matches the available resources.
2. Optimization of the use of crusher machines

   Expectations for the productivity of the crusher machine are very high, there is room to increase the productivity of the machine according to its maximum capacity. This shows that improving the operational efficiency of the machine is very important.
3. Readiness of coal for transportation (hauling team)

   The hauling team faced problems with delays in transporting coal. This indicates the need to focus on increasing the speed of coal readiness to reduce transportation delays.
4. Cycle Time Management

   In addition to the problem of delays, the hauling team also highlighted the cycle time standards that have not been reached. So improvements to the cycle time standard are an important priority to ensure that coal can be transported on time.
5. Crusher machine maintenance

   The Maintenance Team is quite satisfied with the maintenance of the machine. However, there is still room to improve adherence to maintenance schedules to keep the machine running without interruption.
6. Improved performance of crusher equipment (Crusher Operator)

The crusher operator feels that the crusher machine is not working optimally. This condition is a very important area to improve, especially in reducing downtime and increasing daily productivity.

7. Coal transportation accuracy

   The team of hauling equipment operators and dumping men also faced the problem of delays in transporting raw coal to the crusher. So there needs to be an improvement in terms of the accuracy of transportation and arrangements in the stockpile area so that there are no queues that interfere with the production process.

   The main focus of improvement must be directed to optimizing the performance *of the crusher* machine and managing cycle *time* so that the coal production and transportation process run more efficiently. In addition, more realistic production planning *and the timeliness of coal transportation also need to be improved to avoid delays. Even though the maintenance of the crusher machine* is already going well enough, it is still important to adhere to the maintenance schedule so that there are no operational interruptions in the future.

Identify Waste and Process Variation With Current State Mapping

Waste is an activity in the process that does not provide added value for customers, such as waiting time, unnecessary movement, or overproduction, which must be minimized to increase efficiency. Meanwhile, Process Variation is a fluctuation or inconsistency in the way the process is carried out, which can affect the quality, efficiency, and results of the process, whether caused by human, machine, method, material, measurement, or environmental factors.

Current State Mapping *Data Processing*

Current State Mapping is the process of mapping the condition or flow of the coal crushing process that is currently running. The main purpose of current state mapping is to understand how a process operates, identify waste, bottlenecks, or inefficiencies, and become the basis for designing improvements in the next stage.

From the above process, it can be written in a table to explain the time details of each process as follows:

Table 4
Coal Crushing Activity Time Details

Process/Time (Minutes)	Processing Time (PT)	Queue Time (QT)	Lead Time (LT)	Non-Value Added Time (NVAT)	Value Added Time (VAT)
Hauling to CCP (H)	6,0	1,5	9,5	2,0	7,5
Weighing (W)	0,5	1,0	2,0	0,5	1,5
Stockpiling (S)	3,5	3,0	8,5	2,0	6,5

Rehandling (R)	5,0	1,5	8,5	2,0	5,5
Dumping to Hopper (D)	3,0	1,5	6,5	2,0	4,5
Crushing (C)	3,0	0,0	5,0	2,0	3,0
Total (H-W-D-C)	12,5	4,0	23,0	6,5	16,5
Total (H-W-S)	10,0	5,5	20,0	4,5	15,5
Total (R-D-C)	11,0	3,0	20,0	6,0	13,0
Total (H-W-S-R-D-C)	21,0	8,5	40,0	10,5	28,5

In Table 4 there are several things that are the main focus. First, hauling to CCP takes a total of 9.5 minutes, with the time spent on NVAT (Non Value Added Time) as much as 2 minutes. Although it is relatively short, there is potential to reduce NVAT by fixing problems in the transportation process.

Second, in the Weighing process, the time required is relatively short, namely 2 minutes with VAT 1.5 minutes and NVAT 0.5 minutes. However, this process can still be further optimized to minimize waiting times and increase weighing speeds. Third, the stockpiling and rehandling process is a crucial point in the overall workflow. Stockpiling has an NVAT of 2 minutes out of a total time of 8.5 minutes, while rehandling takes a total time of 8.5 minutes with an NVAT of 2 minutes. This activity shows significant waste in both processes, especially because of rehandling which does not add value directly to the product.

Fourth, the dumping to hopper process takes a total of 6.5 minutes, of which the NVAT reaches 2 minutes. This indicates that this process is also less efficient, likely due to variations in hopper capacity that lead to longer wait times. Fifth, the crushing process is relatively efficient with a lead time of 5 minutes and NVAT of only 2 minutes, but there is still room for improvement to be faster, for example by increasing the crusher capacity or reducing the waiting time between loading and crushing.

Analysis of Causative Factors from Production Parameters

Furthermore, the factors causing the non-achievement of production parameters, the data obtained are as follows:

Table 5
Identification of Problems in Production Parameter Aspects

Production Parameters	Key Issues	Types of Waste/Variation Process
Productivity Crusher	The crusher machine is not optimal, and productivity decreases	Defects/Process Variation
	The capacity of the crusher machine does not match the volume of the material.	Process Variation/Overprocessing
	The speed of the feeder breaker in breaking up the material does not match the variation in the size of the material.	Overprocessing/Process Variation

	The stockpile capacity of raw material is often full, causing the feeding process to stop.	Inventory/Waiting
	The feeder breaker is clogged by oversized material	Defects
	Poorly coordinated dumping activities to hoppers	Waiting/Process Variation
	External factors such as bad weather slow down the transportation of materials to the crusher	Transportation/Waiting
	Late start time of the crusher machine	Waiting
	Clock stop crusher too fast.	Waiting
Waiting Material	Delays in transporting materials from the mine	Transportation/Waiting
	There is no coordination in the process of conveying material to the crusher.	Waiting/Process Variation
	The start time of hauling to CCP from PIT is late	Waiting/Transportation

Based on the problems that occur in the productivity crusher in Table 4.40, some of the main factors that cause a decrease in crusher productivity include: the machine not working optimally because the capacity is not balanced with the volume of material being processed, and the feeder speed is not by the variation in the size of the incoming material. In addition, the full capacity of the stockpile causes the feeding process to stop, and the feeder breaker is often clogged by oversized materials, resulting in obstacles in the flow of materials.

Poor coordination problems in the dumping process also add to the inefficiency, coupled with external factors such as bad weather that slows down the transportation of materials. Unscheduled start and stop times of the crusher machine also have an impact on productivity, where the machine starts late and stops earlier than planned.

Meanwhile, in the case of waiting materials, delays in transporting materials from the mine are the main problem. This is due to a lack of coordination in the transportation process, where there is no effective system to regulate the hauling time from the mine to the CCP. As a result, haulage vehicles are often late in starting the journey from the PIT, which slows down the entire process of transporting material to the crusher.

Conclusion

The coal crushing process at PT. XYZ faced the largest type of waste in the form of Waiting with 9 incidents, followed by Defects 6 times, Inventory with 4 incidents, and Process Variation which was quite significant with 5 incidents, while other wastes also contributed to process inefficiency. The most dominant production parameters for productivity underachievement are losses of 605,300 MT and waiting materials of 574,735 MT. Of the total 60 improvement actions carried out, 43 actions (71.67%) have been completed, 12 actions (20%) are still in the process of being worked on, and 5 actions (8.33%) are in the planning stage, with responsibilities spread across three main divisions, namely the Mine Operation Division (MOD) with 26 actions, Technical Support Engineer

(TSE) with 15 actions, and Maintenance (MTC) with 19 actions. The company's operational performance in YTD 2024 (October 2024) showed a significant improvement compared to 2023, especially in the aspects of PA, Productivity, EWH, and OEE, which reflected the success of improving work efficiency and equipment maintenance, with production achievement of 96.8% of the October target and projected to exceed the year-end target. However, UA is still a major challenge with 64% achievement, below the 70% target, so it is necessary to optimize equipment usage time, while OEE increased to 87% close to the 90% target. Overall, the application of the Lean Six Sigma DMAIC method as a managerial tool in increasing coal crushing production at PT. XYZ has provided significant benefits, with production achievements until October 2024 of 9.9 million metric tons (MT) or 94% of the annual target of 10.56 million MT. When compared year-on-year (YoY) with October 2023, there was a 139% increase in production, from only 7.2 million MT in the previous year, reflecting a significant increase in performance in the same period.

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