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Reduce mean time to repair of mining equipment with lean six sigma

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ABSTRACT

A The performance of mining equipment is determined by the reliability of the equipment used, the operating environment, maintenance efficiency, operating processes, and the technical expertise. Therefore, the reliability improvement of equipment is required. This paper aims to present a case study of reducing Mean Time To Repair (MTTR) of the electrical part of coal mining equipment. The mining equipment experienced 19 times of electric failures during 2022, and 42% of them are motor starter failure. These failure impacted equipment down time, which reduce equipment utilization. The research method in this paper is case study utilizing Lean Six Sigma method to resolve the problem. Process analysis has been carry out and the main solution was design special tool for motor starter testing. The results indicated that MTTR reduced from 110 minutes to 10 minutes. Statistical analysis with two sample-t test indicated that improvement results are significant, resulting in Cpk improvement from -2,94 to 6,96. The results of this research show that implementing LSS can effectively reduce MTTR, increase equipment availability, and increase operational efficiency in the mining sector. This research provides insight into the application of LSS in mining equipment maintenance.

1. Introduction

As the size and complexity of mining equipment continue to increase, the impact of equipment failure becomes more significant. The performance of mining equipment is determined by the reliability of the equipment used, the operating environment, maintenance efficiency, operating processes, and the technical expertise of the miner. Therefore, the reliability improvement of equipment is required. One way to improve the reliability is to reduce the mean time to repair (MTTR). The mine production system consists of many subsystems. To increase the profitability and operability of a system, it is essential to optimize each subsystem mutually. The effectiveness of mining equipment is primarily influenced by the system's availability, reliability, maintainability, and ability to deliver expected performance (Barabady and Kumar, 2008). Reliability analysis techniques have gradually become standard tools for improving complex mining systems (Dhillon, 2008, Toraman, 2023; Bangari et al., 2019). Failures cannot be prevented entirely, so it is essential to minimize both the likelihood of failure and the impact if it does occur. A large portion of the operating costs of mining systems are due to unplanned system failures due to unscheduled repairs of the entire system or components. The longer the time needed to fix the failures, the higher the operating cost and the more production opportunity loss will occur since the loss of capacity might occur during the repairing time. Besides that, mining equipment is a high capital investment, and utilization is also essential. Therefore, maintenance tasks are essential to support equipment availability. The primary objective of maintenance is to keep

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production equipment in safe, effective, and intended operating condition so that production and quality goals can be achieved on time and at the lowest cost (Tomlingson, 2009).

In order to support production objectives, equipment availability must meet the availability requirement, and any disruption which causes production to stop must be avoided. To support equipment availability, the maintenance team must fix the failure quickly. The time required to diagnose, fix and recover the failure must be reduced timely. To measure the average time needed to determine the cause of and fix failed equipment, maintenance departments use the mean time to repair (MTTR) as a metric (Ben, Mohamed and Muduli, 2021). MTTR represents the mean time to repair for known repair time data (Tumanggor, 2018). The goal of mining operations is to produce with less capital investment. Production performance depends on availability and utilization, so equipment must operate efficiently. When failure occurs, the repair reaction time (MTTR) must be minimal and recorded for further analysis. In many situations, reaction time is sometimes very short but sometimes needs more time, which might affect productivity. In mining operations as a system, a delay in one section affects the other, finally impacting the production cycle. The frequency and duration of equipment breakdown negatively affect operation productivity and profitability.

This paper aims to reduce the MTTR of the starter motor of mining equipment. The case study was conducted on a coal mining site in Indonesia. The equipment consists of coal hauling dump truck and road maintenance equipment, like motor grader and compactor. All this equipment has its starter motor. When starter motor failure happens, the production team will send the equipment to plant maintenance. The repair of the starter motor was carried out by the maintenance plant team.

Most of the time, longer breakdown time has a triple effect, including loss of production, cost increment and more breakdown experienced. Hence, it is essential to keep maintenance time at a minimum; this can be done by reducing the MTTR. Usually, the time to repair consists of several activities, including time to detect, diagnose, fix and run tests, etc. Reducing time for all these activities will reduce the MTTR. One method to reduce these activities is Lean Six Sigma (LSS). LSS has been widely used for process improvement, as it can improve efficiency, reduce variation and, at the same time, reduce lead time (Raval et al., 2020; Snee, 2010; Antosz et al., 2022; Kęsek et al., 2019).

Mining equipment is some of the most capital-intensive heavy equipment used in the mining industry. Continuously monitoring equipment performance is critical to mining systems. One maintenance approach to measure is time performance, which may affect the production performance (Galatia, 2018). Low equipment reliability is a cost to the company. To this effect, the equipment must be operated and maintained efficiently.

The goal of mining operations is to produce with less capital investment. Production performance depends on availability and utilization, so equipment must operate efficiently. When failure occurs, the repair reaction time (MTTR) must be minimal and recorded for further analysis. In many situations, reaction time is sometimes very short but sometimes needs more time, which might affect productivity. In mining operations as a system, a delay in one section affects the other, finally impacting the production cycle. The frequency and duration of equipment breakdown negatively affect operation productivity and profitability. Most of the time, longer breakdown time has a triple effect, including loss of production, cost increment, and more breakdown experienced. Hence, it is essential to keep maintenance time at a minimum; this can be done by reducing the MTTR.

Mining equipment represents a large capital investment and its reliability directly impacts production efficiency and profitability. Equipment failures, especially long repair times, lead to higher operational costs and production losses. This study addresses a key operational problem: reducing the mean time to repair (MTTR) of motor starters, an essential component of mining vehicles. By applying Lean Six Sigma, the authors demonstrate that systematic process improvements reduce downtime and increase overall equipment availability.

In this case study the mining equipment experienced 19 times of electric failures during 2022, and 42% of them are motor starter failures. The data shows that the MTTR for this problem have exceeded the target 60 minutes. Based on data the actual MTTR was 110 minutes. The motor starter failure impacted loss time in operation, the company decide to improve this problem with aim to reduce loss time.

2. Method

Mean Time to Repair (MTTR)

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MTTR is the time it takes to complete a repair after a failure occurs (Tumanggor, 2018). It is expressed mathematically as the total downtime divided by the number of breakdowns over a period of time (Galatia, 2018). Notification, diagnosis, and repair times are taken into account. This downtime is considered when part removal, adjustment, setup, and testing occur. MTTR are two crucial key performance indicators (KPIs) regarding the availability of a system, plant, equipment, or process. The formula to determine MTTR can be seen in Equation 1 (Ben, Mohamed, and Muduli, 2021).

$$MTTR = \frac{Down\ Time}{Number\ of\ Failure} \quad (1)$$

Mean time to repair refers to the average time required to repair a device or system, expressed as total repair time divided by the total number of repairs (Esmaeili, Bazzazi, and Borna, 2011). An increase in the time taken to fix a failed dump truck or component leads to a low mean time to repair (MTTR).

Lean Six Sigma (LSS)

The main idea of lean is to eliminate all kinds of waste (muda) (Ejsmont et al., 2020). Muda is Javanese term for waste. Seven types of waste include transportation, inventory, motion, waiting, overproduction, over processing, and defect. The concept of Lean originated from the Toyota Production System (TPS). Due to its benefit, some lean principles have been applied in the mining sector (Dunstan et al., 2006; Lööw, 2019). Six Sigma was developed in Motorola in the mid-1980s. Six Sigma is statistical-based problem-solving. As a business improvement approach, Six Sigma focuses on finding and eliminating sources of defects or mistakes that are critical in customers' eyes (Jessica Galdino de Freitas and Ferraz, 2017). The term LSS was introduced around 2000, and LSS teaching started in 2003 as the evolution of Six Sigma (Antony, Snee, and Hoerl, 2017). The goal of LSS is to drive improvement in business (Tampubolon and Purba, 2021). LSS methodology consists of DMAIC (Define, Measure, Analyze, Improve, and Control).

The research uses a case study on the electrical motor component of mining equipment in one of the coal-hauling contractors in Indonesia. An electrical motor is one component attached to the equipment, including a dump truck, compactor, and motor grader. Its function is to convert electrical energy to mechanical energy. They operate using the principle of electromagnetism. Their function is to turn on the engine so it starts operating. When the motor starter breaks down, it must be replaced or repaired. An illustration of a motor starter is described in Fig. 1.

Fig. 1 Motor starter in compactor.

Time to repair baseline data was collected during January to December 2022 period. To reduce MTTR the Time to repair baseline data was collected from January to December 2022. In order to reduce the MTTR, the study follows DMAIC steps. Define the historical data collection of electrical problems during 2022 for all mining equipment, including dump trucks, compactors, motor graders, and backhoe loaders, with 22 unit of equipment. The measure phase calculates the MTTR and utilizes the Pareto diagram. The analysis phase uses process analysis and time study to find the root cause. The improvement phase implements the improvement plan based on input from the preview step. The control phase is to verify the improvement result; in this phase, a two-sample t-test was used to check

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the result's significance before and after improvement. Process capability is also being measured. Minitab software was used for statistical analysis.

3. Result and Discussion

Define Phase

Historical data was collected during the 2022 period. During one year, there were 19 electrical problems, and 42% were motor starter problems or 8 number failures due to motor starter problem. Based on Pareto of failure frequency, the priority focuses on motor starters. The Pareto chart of electrical failure is described in Fig. 2.

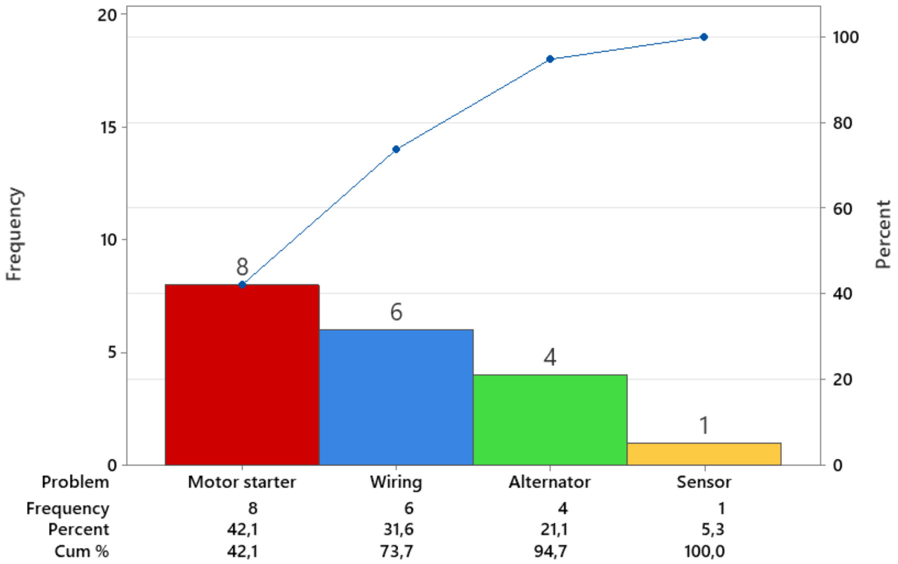

Fig. 2 Pareto chart of electrical failure.

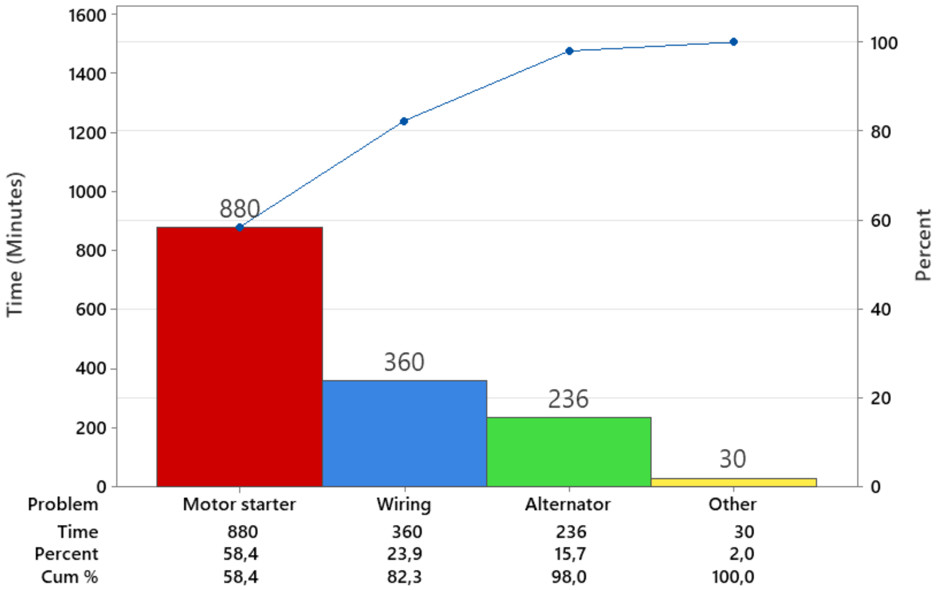

Fig. 3 Pareto chart of electrical breakdown time.

Besides failure frequency, breakdown downtime was also collected, and 58% of the breakdown time was caused by motor starter failure. Pareto downtime as the total down time due to failure described in Figure 3. Motor starter failure contributed to 58% from total down time, it was about 880 minutes down time. It is confirm that failure frequency and time loses due to motor starter. Number of failure and down time data will be used to calculate MTTR as described in Equation 1.

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Measure Phase

The measure phase focuses on measuring the MTTR of the motor starter. MTTR are two crucial key performance indicators (KPIs) regarding the availability of a system, plant, equipment, or process. The formula to determine MTTR can be seen in Equation 1 (Ben, Mohamed, and Muduli, 2021). Calculating MTTR using equation 1 and the result as below:

Down time	: 880 Minutes
Number of failures	: 8
MTTR	: 110 Minutes

MTTR resulted from the mean time to the fixed starter motor failure of 110 minutes.

Analize Phase

The analysis phase is a phase to find out the cause of the problem. Process analysis is carried out to analyze and break down activities into details. Process analysis combined with time study was performed. The main problem is due to excess time for starter motor repair and testing processes. Process analysis is described in Table 1. The average time needed to repair an electric motor is about 110 minutes. This process is divided into several sub-processes, including starter motor removal (20 minutes), repairing time (35 minutes), testing (32 minutes), and reinstallation (21 minutes).

Table 1 Process analysis

Process	Process	Time	Sub Process
Starter Motor Removal		22	Removal of unit battery cables Removal of Starter Motor B+ terminal cable Removal of Starter Motor C terminal cable Removal of the front nut of the Starter Motor Removal of the bolt from the rear of the starter motor Starter Motor Removal
Maintenance / Starter Motor Repair		37	Cleaning the starter motor body and terminals Removal of Starter Motor components Cleaning starter motor components Replacing parts and applying grease to components Reinstallation of components
Starter Motor Testing		33	Take out the battery cable Installation of battery cable on terminal B+ Installation of battery cable on the negative terminal Take out the test cable Perform testing Removal of battery cable at the negative terminal Removal of battery cable at terminal B+
Reinstallation of Starter Motor		23	Installation of rear starter motor bolts Installation of the front Starter Motor nut Installation of starter motor C terminal cable Installation of the starter motor B+ terminal cable Installation of positive and negative battery cables

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Total (minutes)	**115**

Improve Phase

In this phase, an improvement plan is carried out to reduce MTTR. Based on process analysis, some unnecessary activities and motions make testing and repairing time take longer. The main problem is that many activities must be done to prepare for the testing after fixing the motor starter. Since testing is usually performed manually, it requires at least two mechanics to carry out testing. The solution to this problem is an innovation by designing and developing special tools. This tool will reduce the preparation time for the testing process. The device was designed with a plug-and-play mechanism and poka-yoke method. We only need one mechanic to perform the testing process—The solution is described in Table 2.

Table 2 Solution plan

Root cause	**Solution**
Required long time for motor starter testing A lot of activities and motion for testing preparation It requires 2 mechanics for testing preparation	Design special tool for motor starter testing
Electrical short	Poka Yoke device

Process analysis and the time study after improvement were carried out to evaluate the improvement result and result described in Table 3. Some non-added value activities have been reduced; for example, the time to take out the battery and test cables has been reduced to zero. After improvement, the total time required for starter motor testing has reduced from 33 minutes to 1.7 minutes.

Table 3 Improvement result

Process	**Sub Process**	**Actual Average (Before)**	**Actual Average (After)**
Starter Motor Testing	Take out the battery cable	233	0
	Installation of battery cable on terminal B+	248	10
	Installation of battery cable on the negative terminal	208	10
	Take out the test cable	235	0
	Perform testing	373	60
	Removal of battery cable at the negative terminal	361	10
	Removal of battery cable at terminal B+	295	10
Total (seconds)		1953	100
Total (minutes)		33	1,7

Several improvement activities have also been implemented to reduce time for starter motor removal, repair and maintenance, and reinstallation by reducing non-added value activities. All the improvement initiatives lead to total time reduction. The average time to repair before and after improvement has reduced from 110 minutes to 42 minutes, as described in Table 4.

Table 4 Time to repair motor starter

	Time to repair motor starter (minutes)								**Average**
Before	105	109	116	111	111	103	117	110	110
After	42	42	40	40	42	41	42	43	42

In order to validate the improvement result, a statistical test using two-sample t-test has been carried out with a p-value of 0,000, indicating the improvement's significance. The data appear

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normal through the Andeson Darling test with a p-value above 0,05. The individual moving range chart shows the stability of process improvement, as described in Fig. 4.

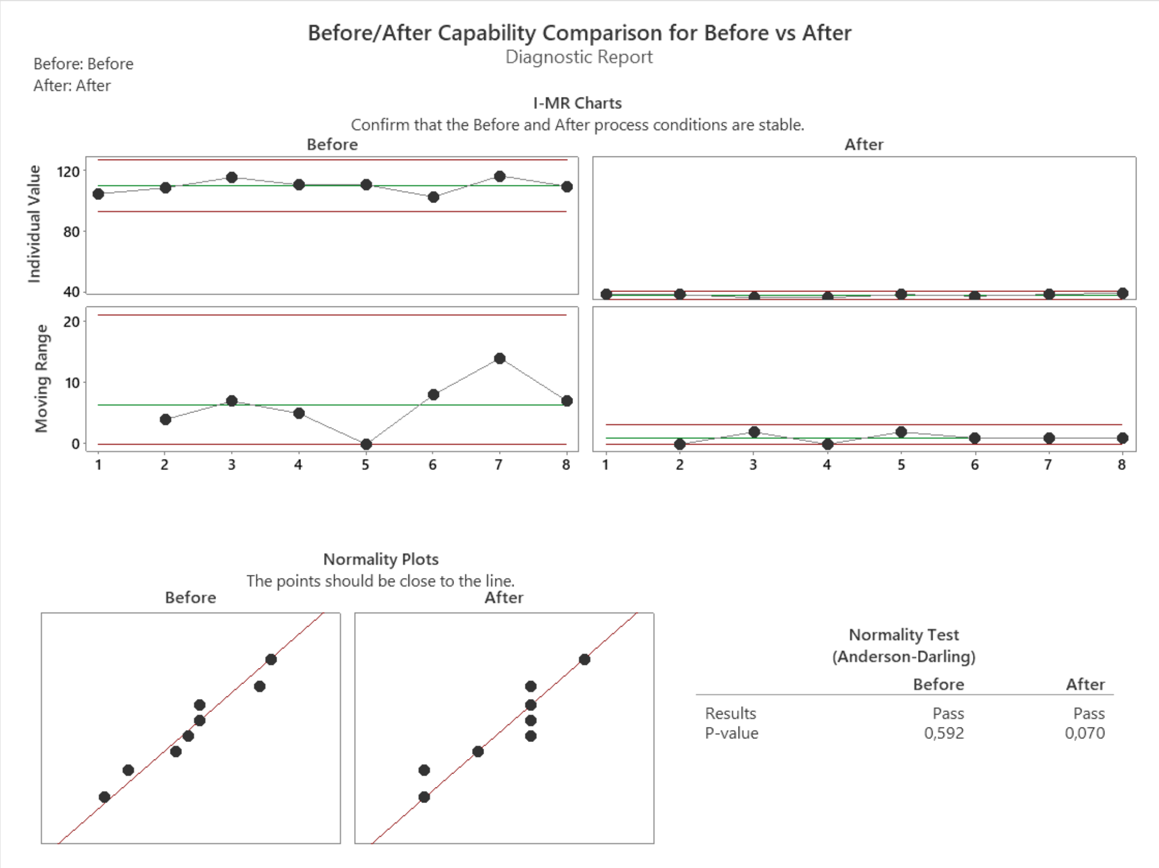

Fig. 4 Individual moving range chart.

The management set the standard for motor starter repair for a maximum of 60 minutes. A process capability analysis was performed using Minitab software to check the process capability—the process capability before improvement described in Fig. 5. Since the target is only one side maximum, the Minitab calculates only process capability indices (cpk) = -2,50. This minus value indicates that the process is out of the specification limit. The standard repair was 60 minutes; however, the actual time was 110 minutes.

The process capability after improvement is described in Fig. 6. Since the target is only one side maximum, the Minitab calculates only process capability indices (cpk) = 6,96. If the process met Cpk= 2 it is equal to 6 sigma (Arthur, 2011). Based on cpk value after improvement (6,96) it indicate that the process performance already above 6 sigma level.

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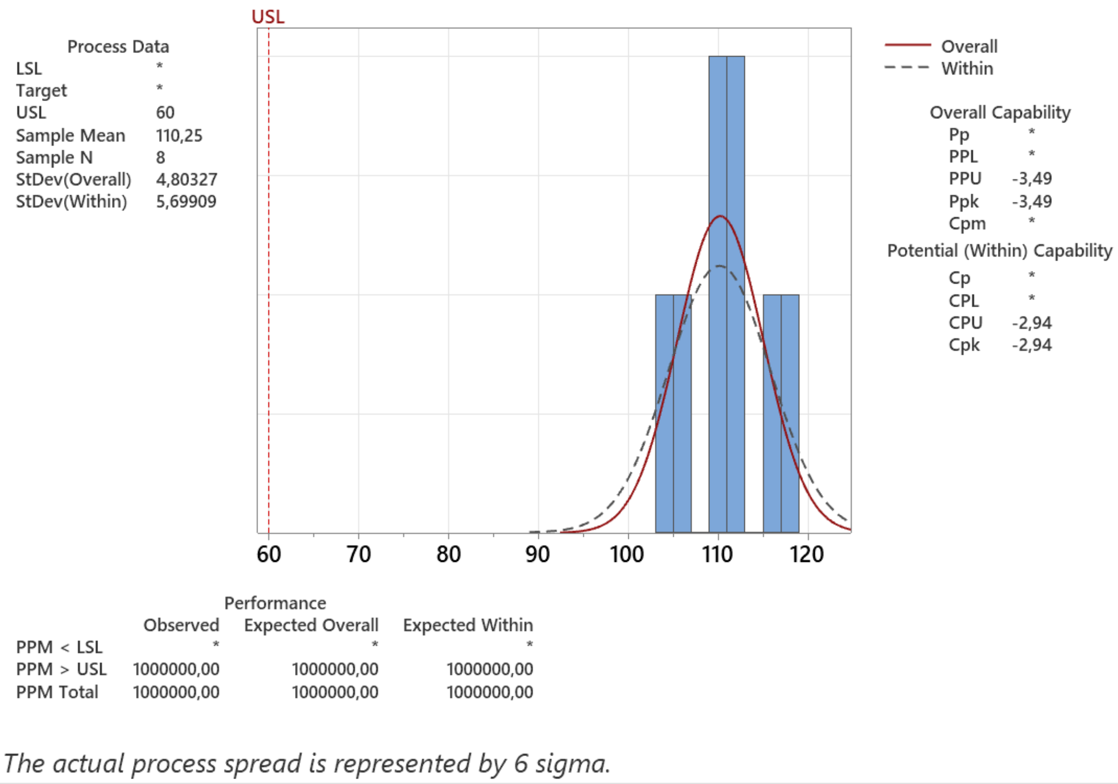

Fig. 5 Process capability before improvement.

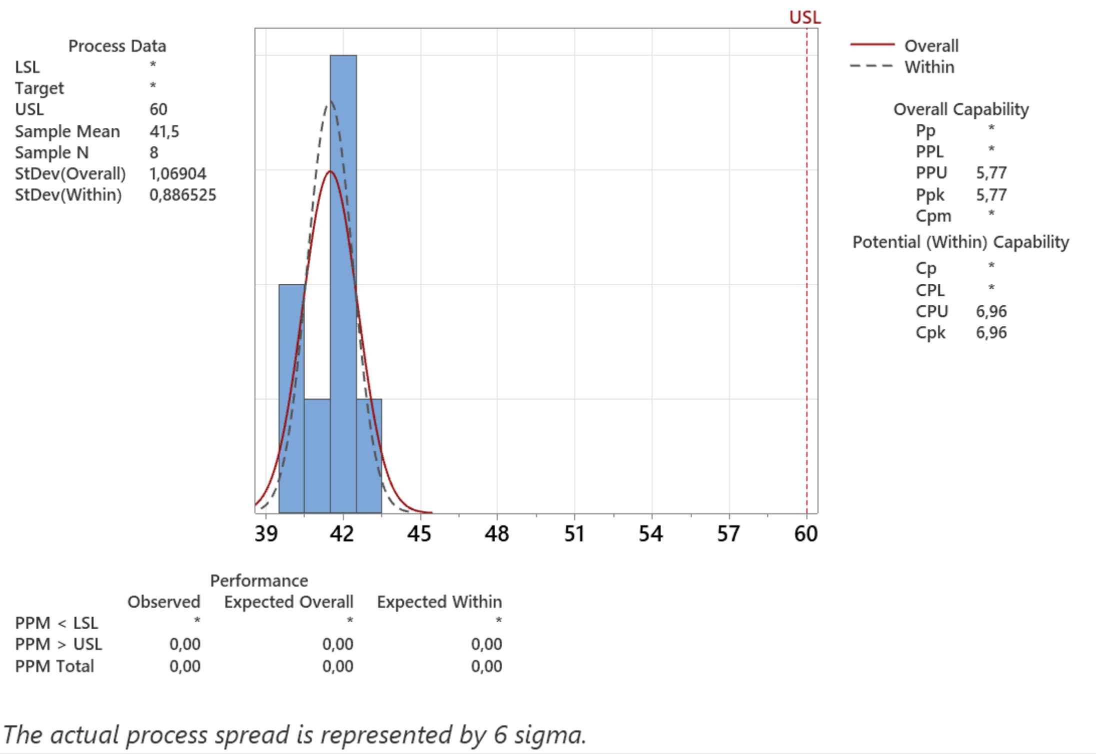

Fig. 6 Process capability after improvement

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Based on the result, it was shown that LSS can be applied in mining equipment maintenance. LSS aim to reduce variation and improve process lead time. This case study is the hard evidence where variation has been reduce from 5,6 to 0.8 standard deviation. Process capability (cpk) also improved from -2,94 to 6,96 means that process are more than capable. Cpk (minus 2,94) indicated that process outside the target. At the same time, MTTR also reduced from 110 minutes to 42 minutes. The study result in line with the preview study (Antosz et al., 2022) found that LSS could improve maintenance process efficiency.

4. Conclusion

Based on the research result, the MTTR has been reduced from 110 minutes to 42 minutes, and the improvement results in a 164%-time reduction. It happens because some non-added value has been minimized by developing and making testing devices that enable mechanics to do testing work rapidly. This initiative came from the mechanic, and the testing device was self-developed to resolve the internal problems. It will enhance the team's motivation since more physical work will be reduced and make the team more productive. Instead of reducing waste, this case study also showed a reduction in variation; standard deviations reduced from 5,4 to 1,0, and Cpk increased from (-2,94) to 6,96. This improvement shows that the lean Six Sigma concept and theory can be applied in mining workshops to reduce MTTR.

This study contributes to adding references to maintenance professionals regarding the application of Lean Six Sigma (LSS) in mining workshops: This study examines the effective implementation of Lean Six Sigma in a mining workshop scenario, proving its ability to minimize MTTR and enhance operational efficiency. The findings indicate that LSS can be efficiently used in mining maintenance process, particularly to reduce equipment downtime through streamlined operations and reduced variation. This approach not only enhanced the repair process, but it also helped to boost team motivation by reducing physical workload. With less physical effort required, the team was able to increase productivity, which is an important aspect in operational performance.

The limitation of this research is that the concept's application might not significantly impact total productivity since it was applied in an electrical system of equipment. However, this can be made as a pilot project and then replicated to more complex mechanical failures, significantly impacting mechanical availability. This structured LSS approach effectively links theoretical LSS principles with practical applications and demonstrates replicability in other contexts. This study focuses on a specific subsystem of mining equipment, acknowledging that it limits its broader impact on overall mining productivity. However, the results could serve as a pilot project for extending Lean Six Sigma applications to more complex mechanical problems in mining systems. Future research could address the application of LSS to predictive maintenance systems and the integration of LSS and real-time monitoring technologies could further improve reliability.

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