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Preventive Maintenance Analysis to Improve the Readiness of Heavy Equipment Hydraulic Excavator Liebherr R9250 & R9350 with Six Sigma Method at PT. XYZ

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ABSTRACT

PT. XYZ is a company in the field of coal mining. The mining production process is carried out by open pit mining, meaning open mining. One of the activities carried out in the production process at PT. XYZ is overburden removal. The excavator used for overburden removal consists of 2 types Liebherr R9250 and R9350. Based on an initial survey, a breakdown occurred on the Liebherr R9250 excavator engine, experiencing a lubrication system failure, and the R9350 experienced a cooling system failure, so the engine was stuck. The purpose of this research is to overcome the problem of unscheduled unit breakdowns on Liebherr R9250 and R9350 hydraulic excavators at the coal mine project PT. XYZ using the Six Sigma method by formulating Define, Measure, Analyze, Improve, Control (DMAIC) that occurs. The results showed that the R9250 and R9350 excavators at the Six Sigma achievement level were in the 1-Sigma category or at the lowest level, with a very uncompetitive description of the quality of the unit's readiness during the production process. This shows that better improvement is needed to support the quality of unit readiness. Based on this research, the recommendations that can be given are that the company needs to improve human resources, monitor spare parts stock, implement maintenance methods, and improve the quality of unit readiness, operation of tools, customizing spare parts specifications, and provision of company facilities.

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1. INTRODUCTION

Coal is a combustible organic mineral, formed from the remains of ancient plants that precipitated and subsequently deformed due to physical and chemical processes that lasted for millions of years. Therefore, coal belongs to the category of fossil fuels. The process that turns plants into coal is called coalification. Coal mining activities require the role of humans as overall design controllers, so the quality of Human Resources has the most influence on mining results. Other supporting roles are also needed in the implementation of the production process properly, such as the role of equipment needed due to limited human labor. There are

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various forms and functions of equipment used in mining. The equipment includes excavators, dump trucks, bulldozers, graders, loaders, compactors, drillers, and so on.

PT. XYZ is a company in the coal mining sector. This company has a level of awareness of quality in every production process. The mining production process is carried out by open pit mining, which means open mining. This mining uses various forms of equipment depending on the production process's function, purpose, and conditions. One of the activities carried out in the production process at the coal mine project PT. XYZ is overburden removal. Each OB point uses one Excavator as a digging tool and four off-highway dump trucks as a transportation tool. At the coal mine project PT. XYZ , the excavators used for overburden removal consist of 2 types, namely Liebherr R9250 and R9350, with 4 units each. At this site, an equipment maintenance system is implemented to prevent the occurrence of unit breakdowns before the service life is complete. The maintenance applied is preventive maintenance and corrective maintenance..

Based on the initial survey after doing preventive maintenance in the field still encountered various kinds of trouble such as hose leakage to fatal that is hose rupture, low power engine, swing tool (boom/stick) and dredger (bucket) wear and tear so that it sounds, the air conditioner is not working, and so forth. In addition, the availability of manpower in the asset department is still limited both from the number of manpower to maintenance expertise. This can affect the readiness of the availability of units that will affect the Mean Time Between Failure (MTBF) on Key Performance Indicators (KPI) as a measure of company performance to determine the ability to achieve targets. Case studies that occur at the coal mine project PT. XYZ efforts that can be made to prevent unwanted things related to equipment damage before the service life is complete are to analyze the problem using Six Sigma. According to Antony (2006) in Herlambang (2020), the Six Sigma concept is proven successful and adopted by the Motorola company so that the rate of product defects can be reduced, productivity increases, customer satisfaction increases, and operational costs are reduced, using practical and effective statistical engineering tools.

Six Sigma is used to find and reduce the factors that cause defects or errors, reduce cycle times and increase productivity. In addition, this method is chosen and applied to maintenance because it can be a solution that focuses on analyzing equipment control before the service life is complete through DMAIC. The stages of DMAIC are determining the problem process (Define), measuring the problem (Measure) by processing MTBF data, analyzing effectiveness (Analyze), applying Root Cause Analysis (RCA) through fishbone diagrams as a cause-and-effect discovery tool to help find reasons for failure or damage in a process, identifying improvements (Improve) through the results of Root Cause Analysis (RCA) which is a structured approach to identifying factors that influence past events so that they can be used to improve performance and proposing improvements (Control). Based on the problems that have been described previously, it is expected that by conducting research using the Six Sigma method (σ) in analyzing the unit breakdown problem during the mining production process at the coal mine project PT. XYZ, with the results in the form of solutions can be input for the company in overcoming the problems faced in the unscheduled unit breakdown.

2. LITERATURE REVIEW

According to Kurniawan (2013) and Sulistyo et al. (2019), maintenance is the activity of maintaining, repairing, replacing, cleaning, adjusting, and inspecting the object being maintained. This concept stems from the human desire to obtain comfort and safety for the objects they own to meet human needs, function properly, and last the desired period. Research by Lubis et al. (2017) in Putra and Irawan (2020), preventive maintenance is a maintenance activity that is carried out in a planned and periodic manner in the form of a schedule; the aim is to reduce the possibility of damage, disruption and maintain facilities. Preventive maintenance is maintenance activities carried out to prevent damage from occurring. The scope of preventive activities includes inspection, lubrication and tuning. While corrective maintenance is a maintenance activity carried out to improve the condition of the equipment until it reaches an acceptable condition (Arsyad and Sultan, 2018). Breakdown maintenance can be defined as a maintenance policy with how the machine or equipment is operated until it is damaged, then only repaired or replaced. This policy is a very crude and unfavorable strategy because it can cause high costs, loss of opportunity to take advantage for the company due to machine stoppages, work safety is not guaranteed, the condition of the machine is unknown and there is no good planning of time, labor and costs (Sudradjat and Megiyanto, 2020).

Research by Assauri (2008) in Pahlevie et al., (2021), equipment management is an activity to effectively organize tool resources to obtain the best results. There are five cycles in equipment management, namely, planning, supplying, operating, maintaining, and finally removing. According to Hardianto (2013) in Tripoli et al. (2018), heavy equipment is a tool that was created to be able to carry out one of the functions or activities that are loading, moving, digging, and so on in an easy, fast, economical, and safe manner. Sometimes, one tool can function in multiple activities, such as an excavator. Besides functioning as a digging tool, it can also function as a loading or transportation tool for a certain distance. According to Sarwandy and Royan (2021), an excavator, backhoe or shovel is a heavy equipment intended to move a material, so that it can relieve heavy work when done with human labor and also to speed up processing time so that it can save time. Kholil (2012) in Pahlevie et al., (2021), heavy equipment used in a construction project is adjusted to the type of work and the function of the tool. As for excavation work, the heavy equipment used is an excavator (backhoe). This heavy equipment serves to dig soil or other materials. The Backhoe is also called a hydraulic digging tool because the bucket used in the tool is hydraulically driven.

Quality is a dynamic condition related to products, people/labor, processes and tasks, and the environment that meets or exceeds customer or consumer expectations. Consumer tastes or expectations of a product constantly change, so product quality must also be adjusted. Changes in product quality require changes or improvements in labor skills, changes in production processes and tasks, and changes in the company environment so that products can meet or exceed consumer expectations (Indrasari, 2019). Quality control is one of the important roles in the company and is directly supervised by the quality control department. The production process that is already running well also has the possibility of product damage. Product damage can occur due to errors in the raw materials, workers, and machines (Setiawati et al., 2020). According to Minh (2016) in Trimarjoko et al. (2020), service quality can be defined by the level of customer satisfaction. While the level of customer satisfaction is a comparison of the type of service received with the expected type of service. Customer satisfaction being one of the most essential goals in an industry, long-term relationship with customers is considered as a top priority goal especially in the service industry.

Gaspersz (2002), basically customers will be satisfied when they receive their expected value. If a product (good or service) is processed at a Six Sigma quality level, then the company may expect 3.4 failures per million opportunities (DPMO) or expect that 99,99966 percent of what the customer expects will be in that product. Thus Six Sigma can be used as a target measure of industrial system performance, about how should a product transaction process between suppliers (industry) and customers (market). The higher the Sigma target achieved, the better the performance of the industrial system. So that 6-Sigma is automatically better than 4-Sigma, better than 3-Sigma. Six Sigma can also be considered a breakthrough strategy that allows companies to make extraordinary (dramatic) improvements on the ground floor. According to Evans and Lindsay (2007) and Kurniawan et al. (2017), Six Sigma is best defined as a business process improvement method that aims to find and reduce factors that cause defects and errors, reduce cycle time and operating costs, increase productivity, better meet customer needs, achieve a higher level of asset utilization, and get a better return on investment in terms of production and service. Research by Gaspersz (2002), Six Sigma has five phases to address specific problems. Here are the steps: (1) Define. Define-formally define process improvement goals that are consistent with customer demand or needs and the company's strategy. Define stage is the first stage in DMAIC methodology. At this stage is to understand the problems being faced to identify the problem in detail. The main purpose of the define stage is to identify the problem precisely, up to describing the problem that is the cause of the discrepancy. This stage begins by defining the stages of maintenance to establish problems in a process, (2) Measure. Measure is measuring the performance of the process at present so that it can be compared with the target set. The measuring stage is the second stage in the DMAIC methodology, where at this stage, the measurement and identification of potential sources of non-conformity that occur in a process will be carried out. Identifying key internal processes affecting CTQs and measuring the failures related to specific CTQs. Actual process capability will be measured at the source of potential nonconformities. This stage begins with determining critical to quality (CTQ), calculating process mean, calculating standard deviation, calculating DPMO, determining Six Sigma level, and through MTBF data analysis, (3) Analyze. Analyze is to analyze the cause and effect relationships of the various factors studied to determine the dominant factors that need to be controlled. At this stage, it detects the main variables that affect failure, defining it as variation outside the boundaries associated with the correct process. Root cause analysis will be conducted using Root Cause Analysis (RCA) in the form of a fishbone diagram. This analysis phase of DMAIC focuses on identifying the causes of nonconformities that affect the company's productivity, (4) Improve. Improve is to optimize the process using root cause analysis (RCA) analyses and others to determine and control conditions optimum process. At this stage, the process will be redesigned and tested. Modify the internal process so the number of failures is within the specified tolerance limits. Once the root cause of the problem is understood, the analysis tool is used to gather ideas to eliminate or solve the problem and improve the performance of measuring variables that can correct the nonconformity. This stage begins by detecting the risks identified during the process while providing improvement recommendations from the RCA, and (5) Control. Control continuously controls the process to improve capability towards the Six Sigma target. The control stage is a stage of controlling proposed improvements. Monitor the modified processes to test that the variables under control remain stable within the set limits. This effort is also expected to implement the proposed improvement results in a certain period. This is the last operational stage in the Six Sigma quality improvement project. At this stage, the results of quality improvement are documented and disseminated, successful best practices in improving processes are standardized and disseminated, procedures are documented and used as standard work guidelines, and transfer of ownership or responsibility from the Six Sigma team to the owner or person in charge of the process, which means the Six Sigma project ends at this stage.

Table 1. Six sigma achievement level

Percentage that Meets Specifications	DPMO	Sigma Level
31%	691.462	1-Sigma
69,20%	308.538	2-Sigma
93,32%	66.807	3-Sigma
99,379%	6.210	4-Sigma
99,977%	233	5-Sigma
99,9997%	3,4	6-Sigma

(Source: Gaspersz, 2002)

According to Rooney and Hauvel (2004), RCA is a process designed and used to investigate and categorize the root causes of events with safety, health, environmental, quality, reliability, and production impacts. RCA is a tool designed to help identify what, how, and why an event occurred. If researchers can determine why an event or failure occurred, they can determine to take corrective actions that prevent future events. Adrianto and Khalil (2015), RCA is a structured approach to identifying influential factors in one or more past events so that they can be used to improve performance. There are various structured evaluation methods to identify the root cause of an undesired outcome. There are five popular methods to identify the root cause of an undesired outcome from simple to complex, namely: (1) Is/Is not comparative analysis, (2) 5 Whys methods, (3) Fishbone diagram, (4) Cause and effect matrix, and (5) Root cause tree.

3. RESEARCH METHOD

Based on several literature studies that discuss quality control, this research raises quality improvement efforts, namely the breakdown problem of the Liebherr R9250 excavator engine experiencing a lubrication system failure and the R9350 experiencing a cooling system failure so that the engine is stuck. The Six Sigma method used in this study is expected to get recommendations for effective improvements to overcome the problem of unscheduled breakdown units on Liebherr R9250 and R9350 hydraulic excavators at the coal mine project PT. XYZ. In general, the methodological strategy carried out in this research that describes the problem, literacy study analysis methods and tools used, and the research steps used in detail are depicted in the research framework, as in Figure 1.

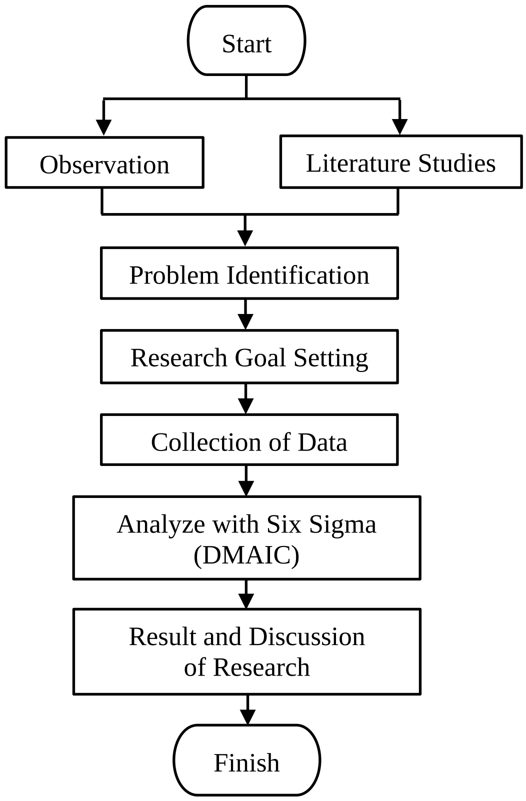

Figure 1. Study Framework

4. RESULT AND DISCUSSION

Define Stage

Define is the first stage in the operation of the Six Sigma method. At the define stage, problems related to the quality of maintenance that occurs at the coal mine project PT. XYZ are defined. After conducting interviews with the asset department, several obstacles were found during the maintenance process. Defining maintenance quality problems based on the production process uses three stages: specific definitions, goal statements, and constraints. (1) Human: Based on preliminary survey results and service package data. One service unit usually consists of 5 to 8 manpower with 1 leading head and 1 supervisor adjust depending on the number of trouble. Scheduling hours meter (HM) has been implemented routinely and orderly, but still found some trouble, namely the processing time that exceeds the estimated duration. This will make time and cost inefficient. In addition, there were some obstacles when the maintenance process took place such as tools lost or lost and tools left behind in the workshop. This obstacle can occur due to human negligence. The number of manpower in the inspection consists of 4 manpower without leading head and supervisor with an estimated duration of 20 minutes. The absence of a leading head or supervisor as a leader or a more experienced person can be less than the maximum inspection carried out, plus a hurry with a predetermined estimated duration. (2) Materials: Based on the initial survey and manual book data, more spare parts are often needed in the warehouse when repairing units. So it takes more time until the spare parts are ready. One way to be done by waiting for availability is to install parts taken from other units, also called the cannibalization process. It was found that the battery parts used needed to be in accordance with the manufacturer's manual book. (3) Method: The method is a sequence of steps that are arranged as best as possible to achieve optimal results. Based on the initial survey and manual book data, there was a discrepancy in the case of the fuel tank maintenance process which sometimes when the service is missed cleaning the dirt around the fuel tank. The methods used in the implementation of maintenance certainly greatly affect the readiness of the unit to achieve production targets. (4) Machine or Equipment: The machine or equipment's performance will determine the production process's results. The better the readiness of the unit, the better the MTBF value, and vice versa. Based on the initial survey, machines or equipment were found that could not be repaired and had to be replaced but were still repaired continuously until a unit breakdown occurred before 80 hours. In addition, the performance of the machine or equipment also depends on the specifications of the spare parts used following the standard manual book. (5) Environment: Based on the initial survey, several problems were found in the mining environment, such as coal production having steep terrain and the location is quite far from the workshop because the R9250 and R9350 excavator units run slowly; therefore, to save time and cost, the maintenance process is carried out directly in the field. Erratic weather can hinder the maintenance process of the unit. When it rains, all activities in the field are canceled to avoid incidents due to slipperiness. When the weather is scorching, it will affect the concentration of manpower performance.

Measure Stage

The measure is the second stage in applying the DMAIC method after going through the define stage. This stage consists of several steps: determining the critical to quality (CTQ) value, calculating the process mean, calculating the standard deviation, calculating DPMO, and determining the Six Sigma level value.

1. Critical To Quality

coal mine project PT. XYZ sets Critical To Quality (CTQ) for each Liebherr R9250 and R9350 Excavator unit that has just undergone maintenance for at least 80 hours to be adequately used before damage or breakdown occurs.

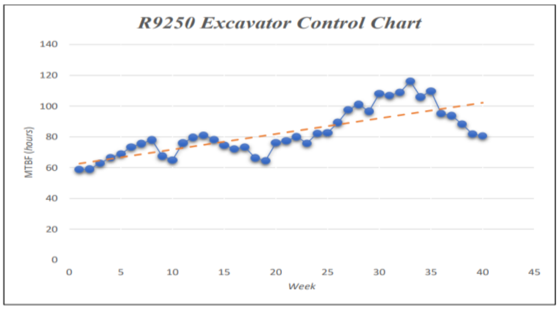

Figure 2. R9250 excavator control chart
(Source: processed data, 2023)

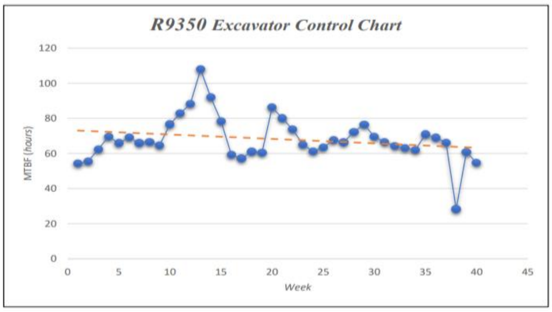

Figure 3. R9350 Excavator Control Chart
(Source: processed data, 2023)

The graph of the P control map in Figure 2 explains the progress of improving and increasing the readiness of the R9250 excavator, while the P control map in Figure 3 is graphically decreasing. This can considerably affect production results because the R9350 excavator can load more, around 38 tons, compared to the R9250, which can load 28 tons.

2. Mean Process

Mean process or average process on Mean Time Between Failure (MTBF) data, by calculating the mean process whose results will be used in the DPMO calculation. The average calculation for the R9250 excavator is as follows.

$$\bar{x}\ R9250 = \frac{\Sigma x_{R\text{-}9250}}{n}$$

$$\bar{x}\ R9250 = \frac{3296{,}86}{40}$$

$$= 82{,}4215$$

Average calculations were performed for the R9350 excavator.

$$\bar{x}\ R9350 = \frac{\Sigma x_{R\text{-}9350}}{n}$$

$$\bar{x}\ R9350 = \frac{2725{,}97}{40}$$

$$= 68{,}14925$$

3. Standard Deviation

Standard deviation is a standard form of deviation from the average value. Standard deviation can be said to be good when the value is smaller than the average value. This calculation process the results can be used in the next calculation, namely DPMO. Standard deviation calculation is done for R9250 excavator with mean of 82,42 and n as much as 40 and for R9350 excavator with mean of 68,149 and n as much as 40. So that the value of standard deviation for R9250 excavator is 15,127 and for R9350 excavator is 12,496.

4. DPMO and Sigma Quality Level

This calculation is based on the results of average equipment readiness, standard deviation and Critical to Quality (CTQ) results on R9250 and R9350 excavators in over burden removal activities. The calculation of Sigma capability value can be obtained by DPMO to Six Sigma conversion table. DPMO value obtained on R9250 excavator is 436411,2. In the Sigma value conversion table, the DPMO value is at a sigma value of 1,67. The calculation of Sigma capability value can be obtained by DPMO to Six Sigma conversion table. DPMO value obtained on R9350 excavator is 828518. In the Sigma value conversion table, the DPMO value is at a sigma value of 0,56.

Analyze Stage

Analyze is the third stage in the DMAIC method after the measure stage. At the analyze stage, DPMO and sigma quality level were analyzed. Furthermore, root cause analysis through RCA (Root Cause Analysis) by making Fishbone or fishbone diagrams to analyze the causes of equipment experiencing unplanned maintenance on Liebherr R9250 and R9350 excavators at coal mine project PT. XYZ.

1. DPMO Value Analysis and Sigma Quality Level

Based on the measurement results at the measurement stage, the application of quality capacity value to Liebherr r9250 and R9350 excavator heavy equipment over burden capacity on coal mine project PT. XYZ for R9250 is at sigma level 1.67 which means that the unit performance is very uncompetitive with a DPMO value applied of 436411.2 hours meets the measurement time for production per one R9350 in accordance with sigma 0.56 which means that the unit performance is very uncompetitive with a DPMO value achieved for 828518 hours meets the measurement time for production per one million opportunities.

The results of these calculations show that with excessive time usage and inefficiency, improving the quality of unit readiness is still necessary. At the 1-Sigma level, the company still needs to improve the quality of machine preparation to reduce wasted time to achieve the Six Sigma target of 3,4 defects per one million opportunities.

2. Root Cause Analysis with Fishbone Diagram

This Diagram is used to identify the cause of a problem from the results of interviews that have been conducted found several factors causing damage to Liebherr R9250 and R9350 excavators. Factors that can affect equipment damage include human factors, materials, methods, equipment and environment.

On Liebherr R9250 and R9350 excavators, the search for factors that cause frequent unscheduled unit breakdowns in the equipment has an impact on low MTBF. Some of the factors that cause unit breakdown during production are human factors, materials, methods, equipment and environment. The following is a fishbone diagram of Liebherr R9250 and R9350 Excavator equipment damage shown in Figure 4 below.

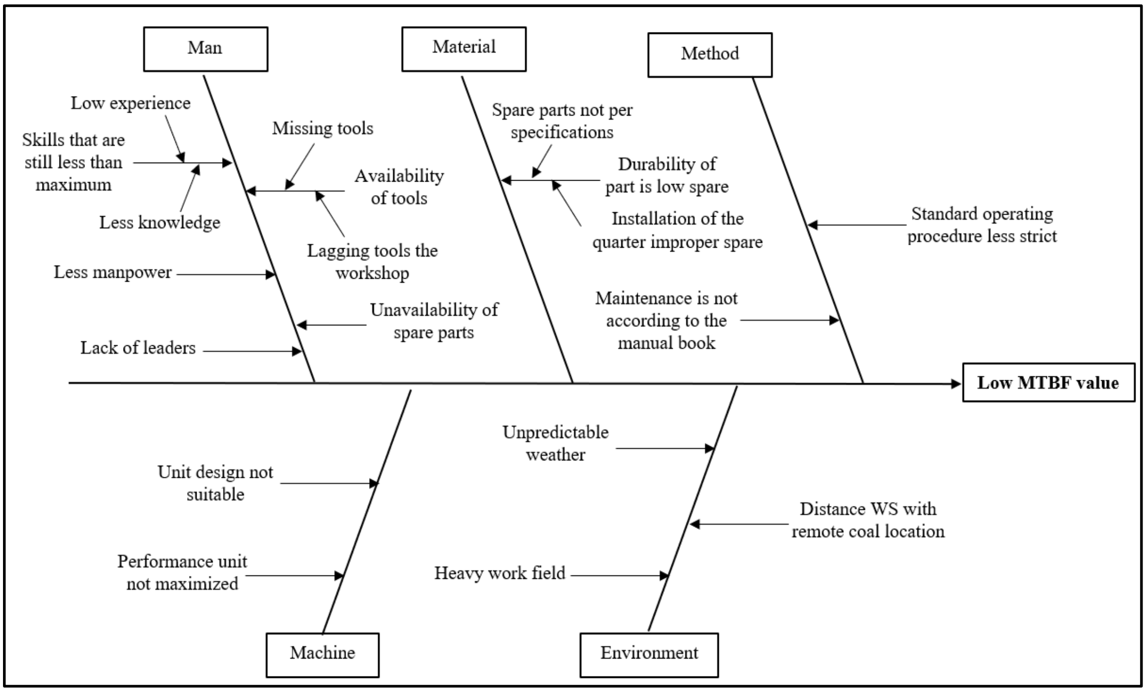

Figure 4. Fishbone diagram

Based on the fishbone diagram shown in Figure 4 shows the factors that cause unit breakdown or damage that affect the low MTBF as follows.

1. Human

The use of heavy equipment in production activities facilitates human labor. The use of heavy equipment must undergo preventive maintenance. This aims to maintain the reliability of heavy equipment and minimize the occurrence of work accidents. Maintenance performed by manpower with limited numbers and skills can result in the impossibility of the maintenance process on the unit. In addition, human negligence in preparing the availability of spare parts and supporting equipment such as tools can waste a lot of time. Tools scattered, lost or missed in the workshop is a form of lack of human accountability.

2. Material

The availability of spare parts is very necessary to support the running of the maintenance process properly. This can save time and reduce costs. Unavailability of spare parts in the warehouse makes the estimated duration becomes inappropriate in the maintenance process. The actual facts that occur in the field when there is a shortage of spare parts will be cannibalism. This will affect the performance of the unit.

3. Method

When the maintenance process takes place there are methods or stages that must be done in accordance with the manual book. Actual facts that occur in the field, there are still some stages that are not done by manpower as in the case of maintenance on replace oil which should be cleaned first on the filter mount so as not to get dirty quickly before the replacement period, but not this stage is often not done by manpower.

4. Machine or Equipment

Good performance on machinery or equipment is the output of the asset department division. The more maximum maintenance carried out by manpower, the better the performance of machine readiness. Vice versa, if a unit design mismatch is found, which results in an unscheduled unit breakdown, it will disrupt the production process.

5. Environment

Maintenance on the excavator unit is carried out directly in the field because the excavator is running slowly. The difference in location between coal production and the workshop is quite far. In unpredictable weather, when it rains, all activities in the field will stop because it is slippery and avoids incidents. When the weather is sweltering, it will interfere with the concentration of manpower performance. In addition, the steep working terrain makes the maintenance process more vigilant.

Improve Stage

Improve stage is the fourth stage in the use of DMAIC method. After analyzing the causes and consequences of Liebherr R9250 & R9350 Excavator damage, then at the improve stage, a plan is determined as a form of improvement to the production process in over burden removal activities at coal mine project PT. XYZ to improve the quality of Six Sigma. At this stage, the results of RCA (Root Cause Analyze) are used to determine and design the best improvement proposals to reduce losses in the company.

1. Improve on equipment damage factors

There are five factors that affect the damage of Liebherr R9250 & R9350 excavators are human, material, method, equipment and environmental factors. Of course, the causes of each factor are different. The following are the results of RCA on equipment damage during the production process that occurs outside the maintenance time by using the causal diagram tools, the factors that cause low Mean Time between Failure (MTBF) are as follows:

a. The human factor focuses on manpowe,
b. Material factors focus on parts availability,
c. Machine or equipment factors focusing on the design of the unit, and
d. Environmental factors focus on location distance, terrain and weather.

2. Improve equipment damage control

Based on the stages that have been passed, the next step is to improve the equipment damage control. At this stage will be given a proposal for the company on the quality of the readiness of heavy equipment in the production process.

Table 2. Proposed quality control

Conditions Before Control	Proposed Control Measures
1. Human Factors Implementation of maintenance is less than the maximum due to limited skills and the number of manpower. In addition, it occurred due to human negligence in preparing the availability of spare parts and supporting equipment at coal mine project PT. XYZ.	Proposed suggestions for quality control of machine readiness to improve the recommended MTBF for the company can be applied as follows. a. Perform the implementation of once a month maintenance training both basic and advance knowledge, b. Provide full support for the implementation of improvement by appreciating the improvement ideas implemented, c. Create a work program of reward and punishment. Rewards will be given to employees who perform well. Punishment will be given to employees who violate the SOP as applied to the company.The implementation of this work program will make the human resources in coal mine project PT. XYZ company increase because it will continue to be encouraged to display the best possible performance, d. Candidate must possess at least a bachelor's Degree, Engineering (Computer / Telecommunication), Engineering (Computer / Telecommunication) or equivalent. How the solution provided by the dealer regarding the understanding of its parts to manpower will be very helpful in the repair process, e. Candidate must possess at least a bachelor's degree,master's Degree / Post Graduate Degree, f. Must comply with company SOP, g. Routine checks related to the availability of spare parts to always be ready, h. Routine checks are carried out related to the readiness and availability of supporting equipment, and i. Always remind each other about the tools that will be used or tools that have been used to immediately tidy up again.
2. Material Factors Unavailability of spare parts standby in the warehouse as a form of preparation.	a. Increase the availability of spare parts in the warehouse, and b. Working closely with the vendor as a provider and supply of spare parts for the availability of spare parts are always ready.
3. Method Factors Application of inappropriate system maintenance methods and standard operating procedures less stringent.	a. The application of the maintenance system must be in accordance with the manufacturer's manual book, b. Create and adhere strictly to the Standard Operating Procedures (SOP) maintenance system, operating system tools, and other systems, and c. Benchmarking the maintenance system.
4. Machine or Equipment Factors Non-compliance with specifications or designs used on the unit can interfere with unit readiness performance resulting in unit breakdown.	a. Communication with the dealer, and b. Regular implementation of socialization related to the importance of unit readiness performance.
5. Environment Factors The location is far from the warehouse, therefore maintenance excavator R9250 and R9350 is not done in the warehouse but in the field. Erratic weather and steep work terrain can affect the concentration of manpower that will affect the performance of manpower and quality of maintenance.	a. Making a special place for supporting tools closer to the location, b. Regular implementation of socialization related to environmental factors to the maintenance process, and c. Provide shelter facilities in the field.

(Source: processed data, 2023)

Control Stage

The control stage is the last stage of using the DMAIC method to improve production quality in the face of Liebherr R9250 and R9350 Excavator equipment damage. The control stage is carried out by following up on the results of the proposed improvements from the improvement stage. This stage aims to monitor or control whether the maintenance process is running as expected. The steps that can be taken in this control stage are as follows: (1) Good communication and interpersonal skills, (2) Perform periodic monitoring of manpower performance, (3) Conduct periodic monitoring of spare parts, (4) Conduct periodic supervision of the use of tools, (5) Perform maximum maintenance on excavator units R9250 and R9350, especially on components that often cause damage, and (6) Provide field facilities such as shelter. After analysis using Six Sigma method, it is expected that this study can be used as input and information to the coal mine project PT. XYZ regarding suggestions for improvements in the production process in order to control the unscheduled breakdown unit.

5. CONCLUSION

Based on this research, the results obtained from the calculation at the measure stage by analyzing the Mean Time Between Failure (MTBF) data that starts from the Critical To Quality (CTQ) determined to be for 80 hours on both units. On the R9250 excavator, the average or mean result on MTBF data processing is 82,42 and a standard deviation of 15,127, with a DPMO value obtained of 436411,2, which is at a Sigma value of 1,67. On the R9350 excavator, the average or mean results in MTBF data processing are 68.149 and a standard deviation of 12,496, with a DPMO value obtained of 828518, which is at a Sigma value of 0,56. A conclusion is drawn through the Sigma value that the R9250 and R9350 excavators are at the Six Sigma level of achievement, which is in the 1-Sigma category, which is at the lowest level with a very uncompetitive description of the quality of the unit's readiness during the production process. So, better improvement is needed to support improving the quality of unit readiness. Recommendations that can be given are the company needs to increase human resources, monitoring stock of spare parts, the application of maintenance methods and operation of equipment, adjusting the specifications of spare parts, and the provision of corporate facilities. Suggestions for further researchers are expected to be able to control the proposed improvements that have been given to improve the quality of heavy equipment readiness in the company. In addition, further researchers can also use other quality control methods to be compared with Six Sigma quality control methods in this study.

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