

The Measurement and Improvement of Effectiveness in K-440 Haul Truck Using Overall Equipment Effectiveness in Coal Mining Company

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Abstract - The aims of this study were to determine the effectiveness of K-440 haul trucks based on Overall Equipment Effectiveness (OEE) calculation, to find out the main factors that caused the ineffectiveness of K-440 haul trucks based on fishbone diagram and Failure Mode and Effect Analysis (FMEA), as well as to analyze the proposed implementation of appropriate improvements to overcome the main problems of K-440 haul trucks. The method applied was the mixed method, and the type of research was descriptive. The analysis used OEE, fishbone diagram, and FMEA. The results show that the average effectiveness of the three K-440 haul trucks is still far below international standards, which is 44,99%. The material is a significant factor that causes low OEE based on fishbone diagram analysis. There are five problems based on the Risk Priority Number (RPN) critical value from FMEA analysis, namely transmission which is not functioning properly, worn brake lining, unrotated propeller shaft on the shaft, cracked brake drum, and broken spring. Then, the implementation of eight pillars of Total Productive Maintenance (TPM) is proposed in overcoming the main problem of K-440 haul trucks. Based on these results, the company needs to implement eight pillars of TPM and carry out OEE calculations regularly.

Keywords: measurement effectiveness, improvement effectiveness, haul truck, overall equipment effectiveness

I. INTRODUCTION

The rich abundant natural resources in Indonesia is an opportunity for industry players to use it. One industry that continues to grow and is one of the backbones of the Indonesian economy is the coal mining industry. Coal has various benefits, including being a power source for

electricity generation, the main fuel for the production of steel, cement, aluminum, and other industrial activities. Coal is a reliable energy source to be used as a steam power plant compared to other electricity sources (Arvirianty, 2018).

The research discusses one of the coal mining companies that has been engaging in coal mining since 2007 with mine sites in the East Kalimantan. It is one of many companies that get permission to export coal. It exports coal to several countries in Asia, such as Philippines, Pakistan, and India which are the main export destinations. As a coal mining company, it has also experienced coal price fluctuations that sometimes harm the company's finances. Therefore, this company needs to improve its effectiveness to optimize the production costs that have been incurred. One of the ways that can increase the effectiveness of production in the mining industry is to optimize the use of heavy equipment during the mining process. Measuring the effectiveness of heavy equipment usage is one of the important factors to support the success of the production process.

In a coal mining, there is a series of activities that must be carried out starting from land clearing, overburden removal, getting and hauling coal, and the breakdown of coal (crushing). The main activity in the coal mining process is coal getting, which is the process of extracting coal to be transported and hauled. It is the transportation of coal from the mine (pit) to the stockpile/run of mine. Heavy equipment used in coal getting activities is loaders to dredge coal and put it into haul trucks. Then, in hauling activities, haul trucks are used to transport coal from the pit (mining location) to stockpile. The coal is deposited before being inserted to the coal shredder (crusher). This company uses EC-480 loaders for coal getting and K-440 haul trucks for hauling activities.

Table 1 presents the average breakdown of haul truck

and loaders in 2017-2018. The breakdown is a condition in which the unit or machine stops producing or operates for a certain period of time due to damage (Alam, Mahanta, & Nawghade, 2018). Based on data in Table 1 comparing the average breakdown of K-440 haul trucks with EC-480 loaders in 2017-2018, the K-440 haul trucks have a breakdown time much higher than the EC-480 loader.

Table 1 Average Breakdown of Haul Trucks and Loaders in 2017-2018

Year	Breakdown of Haul Truck K 440 (hour)	Breakdown of Loader EC 480 (hour)
2017	2.058,58	1.302,15
2018	2.087,45	1.344,47
Total	4.146,03	2.646,62

(Source: The Researchers, 2019)

Table 2 shows the K-440 haul trucks' breakdown in haul trucks that have the highest breakdown time in 2017-2018. It consists of three units with numbers of STRL44G042, STRL44G055, and STRL44G058. This company conducts mining processes 24 hours a day. Therefore, the availability of tools has an important role in mining activities carried out by this company. The breakdown experienced by haul trucks is still a problem because of the expectations coal mining company. The haul trucks can continue to be used for 24 hours every day without breakdown with haul trucks not operating for 6 hours every month during the periodical services. The high operating hours of the K-440 haul trucks makes this company need to investigate further the condition of the K-440 haul trucks and carry out planned maintenance activities.

Table 2 Breakdown of Three K-440 Haul Trucks in 2017-2018 in Hours

Year	STRL44G042	STRL44G055	STRL44G058
2017	2.056,87	1.942,35	2.176,51
2018	2.074,3	1.918,05	2.270,01
Total	4.131,17	3.860,4	4.446,52

(Source: The Researchers, 2019)

Based on previous research conducted by Chong, Ng, and Goh (2015), the problem faced in their research was the high machine downtime at operational time. It caused the value of Overall Equipment Effectiveness (OEE) to be below international standards (85%). To overcome this problem, they identified the causes of high downtime on machines using the Failure Mode and Effect Analysis (FMEA) method. Priority for corrective action was based on the obtained Risk Priority Number (RPN). The highest RPN value was in the bond head component - spring rotary BH reference holder, which was 80. The action taken to increase the value of OEE was to carry out autonomous

maintenance by conducting cleaning activities. The results after taking the corrective actions within two months, the OEE value increased to 81,7%.

Susilo and Andika (2016) faced the low OEE value caused by frequent engine stops for a long time during the production period. To overcome this problem, they used the FMEA method to identify the cause of failure in the packaging material. The results of FMEA showed that the component of silica gel became the component that had the highest RPN value, which was 280 with the severity value of 7 and the occurrence value of 8 affecting the process. Furthermore, an analysis was carried out using a fishbone diagram to find out the cause of the engine stopping. It was known that sensors in the engine, filling speed, closing speed, cutting silica gel, operator capability, material laying, operator movement, and product variation were the causes of the engine stopping for a long time. To increase the OEE value in the packaging process, they suggested that the company implemented the Total Productive Maintenance (TPM) pillar, namely 5S by autonomous maintenance, planned maintenance, quality maintenance, and training.

Based on the problems faced by the company and by considering several studies in previous research, researchers use an operational management approach, specifically about maintenance. Maintenance includes all activities that aim to keep the equipment functioning. TPM combines the concept of Total Quality Management (TQM) with a view of strategic maintenance from the process and design of equipment for preventive maintenance (Heizer, Render, & Munson, 2017). One of the basic measurements related to TPM is OEE. It is the right measurement of performance for overall machine effectiveness to increase productivity (Tobe, Widhiyanuriyawan, & Yuliaty, 2017; Roessler & Abele, 2015; Zammori, 2015).

According to Tsarouhas (2015), The OEE is a metric to improve system productivity and to reveal the hidden costs associated with the efficiency of the equipment. The OEE concept is to ensure that the machine works or produce as much as it is supposed to produce (Teoh, Ito, & Perumal, 2017). Furthermore, OEE also becomes the basis of business improvement strategies that handle the underlying losses causing reduce in equipment efficiency (Binti Aminuddin, Garza-Reyes, Kumar, Antony, & Rocha-Lona, 2016).

OEE is a measurement method used in the manufacturing industry by combining availability, performance, and quality to evaluate the effectiveness of tools/machines. Then, it is expanded to measure the effectiveness of major open mining tools such as shovels and trucks (Sarkhel & Dey, 2017; Charaf & Ding, 2015). So far, many previous studies using the OEE method have focused on manufacturing companies such as Chong *et al.* (2015), Nallusamy and Majumdar (2017), Ranjan and Mishra (2016), Shakil and Parvez (2018), Singh and Narwal (2017), Susilo and Andika (2016), and Tobe *et al.* (2017). However, there are not many studies in the mining industry, especially coal mining. The OEE research conducted in this study enriches research related to coal mining.

Based on the mentioned description, the purpose of this study is to determine the effectiveness of K-440 haul trucks based on OEE calculation results. Next, the researchers also try to find out the main factors causing the ineffectiveness of K-440 haul trucks based on fishbone diagram analysis and FMEA. Then, the researchers will analyze the proposed implementation of appropriate improvements to overcome the main factors problems with the K-440 haul trucks.

The results of this study are expected to be used as input for companies in optimizing the use of haul trucks and minimizing breakdown time through the application of TPM. Then, the calculation results using the OEE method can be used as a basis for evaluation by companies.

II. METHODS

The research method is a mixed-method which combines quantitative and qualitative methods. According to Sekaran and Bougie (2016), the mixed method focuses on the collection, analysis, and mixing of quantitative and qualitative data in one or a series of studies. The type of research is descriptive. Descriptive research is conducted to collect data that describes the characteristics of objects such as people, organizations, products, or brands, events, or situations (Sekaran & Bougie, 2016). The unit of analysis is a coal mining company. The unit of analysis refers to the level of aggregation of data collected during the data analysis stage (Sekaran & Bougie, 2016). This study uses a cross-sectional time horizon because it is only done at a certain time. The researchers present a framework of this research in Figure 1.

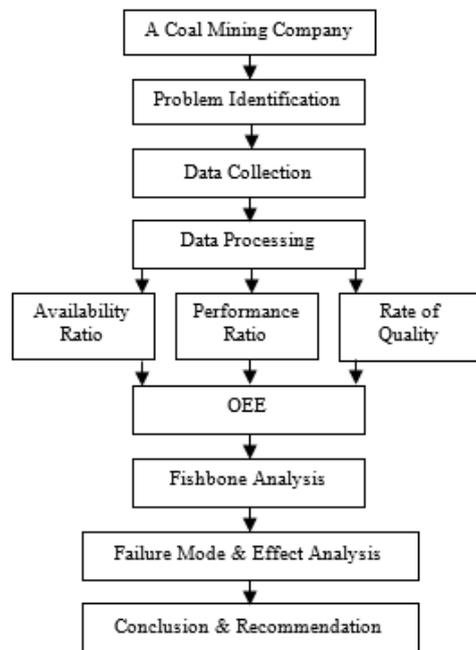


Figure 1 Research Framework
(Source: The Researchers, 2019)

The data are quantitative data and qualitative data with primary data and secondary data. Data collected are obtained from interviews with Plant Assistant Managers of the coal mining company and direct observation by visiting the site in the East Kalimantan. The results of the interview obtain data from 2017 to 2018 in the form of haul trucks and loader breakdown data, monthly maintenance time, shift change, break and lunch, speed losses, loading times loss, the volume of average load, bucket capacity, human factors, methods, materials. The environment that affects the condition of the K-440 haul trucks, and the frequency of damage to the components.

The data analysis method is OEE, fishbone diagram, FMEA, and TPM. Calculations using OEE method to

measure the effectiveness of haul trucks, followed by further analysis using fishbone diagrams and FMEA method. It is to find out the priority of problems that must be addressed immediately. Finally, the researchers provide recommendations for applying TPM pillars to overcome the main factors of the problem.

III. RESULTS AND DISCUSSIONS

Table 3 The Calculation of OEE
in K-440Haul Trucks in 2017-2018

Unit	International Standard Values	Availability	Performance	Quality	OEE
STRL 44G042	90%	62,72%	75,51%	94,39%	44,71%
STRL 44G055	95%	64,39%	76,10%	95,29%	46,69%
STRL 44G058	99%	60,95%	75,37%	94,83%	43,56%
Total	85%	62,69%	75,66%	94,84%	44,99%

(Source: The Researchers, 2019)

Table 3 shows the results based on the calculation of OEE factors (availability, performance, and quality). According to Elevli and Elevli in Waqas, Tariq, Shahzad, Ali, and Saqib (2015), the value of the OEE international standard is 85%. Based on the OEE calculation results on the K-440 haul trucks, it can be observed that it is still far below the standard. The average OEE value of the three K-440 haul trucks as a whole is only 44,99%. This result is similar to the OEE result by Susilo and Andika (2016). They agreed that the OEE rate was also below standard (49,45% to 62,07%). Then, they also used fishbone analysis to analyze the factors causing low OEE.

Based on the results of interviews conducted by Plant Assistant Manager of the coal mining company, several factors are affecting the performance of the K-440 haul trucks. Those cause a low OEE value as presented in the fishbone diagram in Figure 2. The detail explanation of the factors in the fishbone diagram is described in several points. First, human factors are influenced by the lack of knowledge about the standard operating of the K-440 haul trucks. This type of truck is from Europe. Generally, operators are more familiar with the units from Japan. This issue is caused by a lack of refresher training conducted by the company. In addition, operators often ignore the daily examination program, which is a Standard Operating Procedure (SOP) before operating it every day. The operators also do not care about the field that will be passed so that it often causes the unit to experience severe impacts.

Second, the engine factor is influenced by the age of haul trucks. It has been long enough or past the usage period. Thus, the damage from all components will get worse even though it has been repaired.

Third, the main factor that influences the low OEE value is material. This material factor is influenced by the replacement of components/materials that are not in accordance with the manufacturing standards and reuse of

old major component parts during periodical services. It aims to minimize the cost of purchasing new components. In addition, the companies using local spare parts are easier to obtain due to the late arrival of genuine spare parts. Thus, it causes the duration of repair to be longer. The minor components such as the brake lining and brake drum do not function optimally because the service life is up.

Fourth, the method factor is influenced by poorly organized maintenance. It can be periodical services that are not carried out on time. It is not carried out on a certain time, and general overhauls are often not carried out by mechanics. In addition, the company still often applies the run to fail system, which is only replacing the damaged components/materials.

Fifth, environmental factors are influenced by the heavy field of work because the road passed by the K-440 haul trucks is not off-road. The grade of the route passed is quite high with many inclines. Besides, road conditions that are dusty and muddy also affect the performance of the unit.

After using fishbone diagrams, the researchers found that the material has the most factors which cause a low value (OEE). Furthermore, the researchers carry out further analysis using FMEA to measure each failure mode based on three parameters, namely severity (S), occurrence (O), and detection (D). Then, it is multiplied to get the RPN value. Recommendations for improvement are made by calculating the critical value of RPN first, as explained by Febriyanti and Fatma (2018). After RPN value is obtained, it is sorted from the highest and lowest values to determine the priority of the corrective action. The calculation of RPN is presented in Table 4.

Pillars of TPM that can be applied maintenance activities of K-440 haul trucks consist of several points. First, the company can carry out autonomous maintenance in a disciplined manner by involving operators in maintaining K-440 haul trucks. It can be done by following the existing SOPs well. For example, it is by ensuring operators not to miss the daily inspection program and do unit cleaning or unit washing before periodical service to maximize mechanical inspections. The company can also make a check sheet of components to be filled out by the operator.

Thus, when the daily examination program is carried out, the operator reporting on the condition of the K-440 haul trucks can be more detailed.

Second, the company should develop a maintenance plan that has been carried out by the company in accordance with a predetermined schedule. They should also make a thorough checking procedure based on the frequency of damage occurred during previous periodical services to minimize the potential damage to the K-440 haul trucks. Third, the company can improve maintenance quality by evaluating and repairing damage to the unit using root cause analysis.

Fourth, the company should focus on the improvement by forming a special unit. It can consist of a plant department, and engineering representatives can also be an option. This is done to find a comprehensive solution to the problem of K-440 haul trucks.

Fifth, the company should perform early equipment management by using a database of previous repair and maintenance activities. It is to ensure that when the company uses new units in the future, it can achieve optimal performance. Sixth, the company must conduct training to increase the knowledge of the operators, mechanics, and managers to achieve TPM goals. In addition, the intensity of refresher training needs to be carried out routinely every three months to improve the skills and knowledge of K-440 haul trucks operators. It can be done by reminding the company's SOP and explaining its benefits to operators so that operators can minimize the damage of K-440 haul trucks.

Seventh, the company should ensure that the safety, health, and environment at the mining location are maintained. It is done by providing routine counseling to all employees regarding the importance of safety in work. In addition, the company needs to maintain the condition of the hauling lane to minimize damage to the component of the K-440 haul trucks and prevent accidents caused by the damaged hauling lane. Last, the company can implement TPM in administrative and support departments by creating a database. It supports the production process, especially in determining the inventory of spare parts.

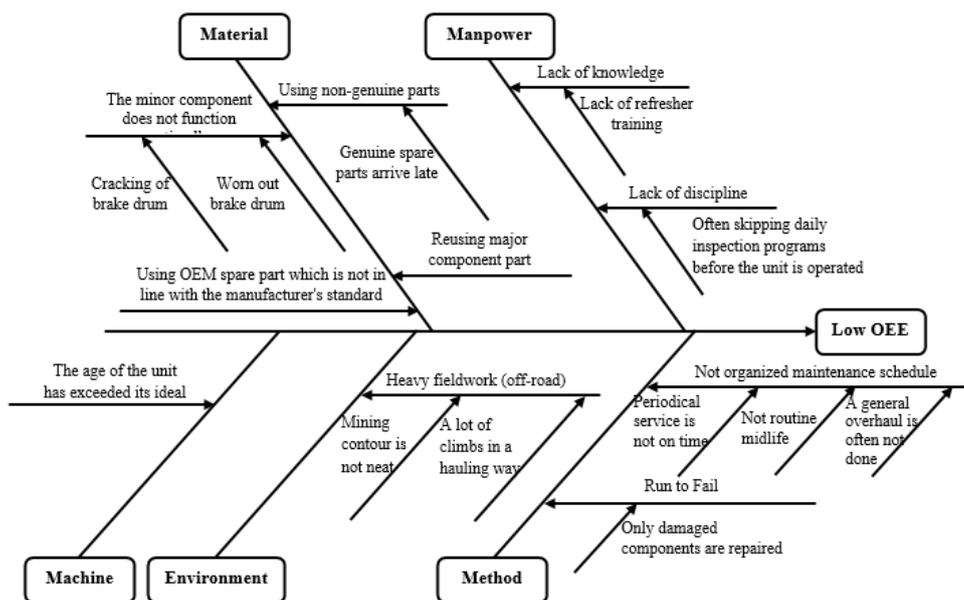


Figure 2 Fishbone Diagram (Source: The Researchers, 2019)

Table 4 Risk Priority Number (RPN)

Rank	Potential Failure Mode(s)	Potential Effect(s) of Failure	S (1-10)	Potential Cause(s) of Failure	O (1-10)	Current Controls	D (1-10)	RPN
1	The transmission does not function properly	The trucks cannot operate because the gear speed cannot adjust to the load	10	The transmission synchronizer experiences excessive heat	6	Refresher training to operators is done, and the damaged spare parts are replaced/ overhauled	9	540
2	Brake lining is worn out	The braking system does not function optimally because the brake lining is thin	6	The hauling line is a high grade (climbs & derivatives), so braking is often done	7	Refresher training to operators is done, and the worn brake lining is replaced	7	294
3	The propeller shaft does not rotate on its axis	The truck cannot operate because of the damage in the center bearing	9	Center bearing is worn out	6	Lubricants in the form of grease are provided at each center bearing for periodical service	5	270
4	The brake drum is cracked	The braking system does not operate optimally because the brake drum is running low due to friction between the brake shoes and the drum (potentially the drum breaks due to heat)	5	The hauling line is a high grade (climbs & derivatives), so braking is often done	7	Refresher training to operators is done, and the cracked brake lining is replaced	7	245
5	Spring is broken	Trucks cannot be given ideal loads because the fulcrum is damaged	7	Road conditions and non-genuine spare parts cause it	8	The load is tightened to ease the burden	4	224

(Source: The Researchers, 2019)

IV. CONCLUSIONS

The main finding of this research is the OEE value of K-440 haul trucks for the 2017-2018 period with the unit number of STRL44G042 with 44,71%, STRL44G055 with 46,69%, and STRL44G058 with 43,56%. The overall average is 44,99%. In other words, it never reaches the established international standard, which is 85%. Material factors are the main factors causing the low OEE value based on the results of the fishbone diagram analysis. Five problems are above the critical value of RPN based on FMEA analysis. Those are the transmission does not function properly, brake lining wears off, propeller shaft does not rotate on the shaft, brake drum is cracked, and spring is broken. The application of eight TPM pillars is proposed in overcoming the main problems in K-440 haul trucks.

The coal mining company discussed in this research is suggested to regularly calculate OEE to determine the effectiveness of the K-440 haul trucks. It can also evaluate the causes of problems in the K-440 haul trucks using fishbone diagram analysis. FMEA can find out the priority issues to be immediately addressed by the company, and implement eight TPM pillars in K-440 haul trucks' maintenance activities.

This research contributes to enrich the study of OEE in the mining industry. Many previous research on this topic are mainly focusing on manufacturing than the mining industry. The limitation of this research is the measured efficiency by only considering the individual equipment efficiency, in this case, K-440 haul trucks. Thus, the results cannot be generalized.

Future research can extend it into not only the manufacturing or mining industry but also the service industry with Overall Service Effectiveness. Thus, future research is suggested to enrich the research of Overall Service Effectiveness in the service industry.

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