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Integration of FMEA method and overall equipment effectiveness to increase effectiveness of TS analyzer machine

Welly Atikno*, Lien Herliani Kusumah

Department of Master Industrial Engineering, Universitas Mercu Buana, Jl. Meruya Selatan No.1 Kembangan, Jakarta 11650, Indonesia

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A B S T R A C T

Total Sulfur Analyzer (TS Analyzer) is one of the machines in the laboratory to test the total sulfur content contained in coal samples. Technically, specifications and use are regulated by international standards. In 2020, the downtime of these tools was very high, causing the productivity of surveyors to decrease. Low productivity will have an impact on the company's losses. The productivity of this equipment and machines is crucial to maintaining the company's success in its business processes. This study aims to measure the effectiveness of the operational performance of the TS Analyzer machine in the laboratory, analyze the causative factors and make improvements. This research uses the integration method of Failure Mode And Effect Analysis (FMEA) and Overall Equipment Effectiveness (OEE). Based on the analysis of the causes of the problem, the low OEE value is caused by the high breakdown loss. Based on the FMEA analysis, it was found that the operator was wrong in operating the machine with RPN 343, electrical instability with RPN 343, unstable temperature with RPN 343 and improper thermocouple installation. The results showed that the OEE value of the TS Analyzer machine has increased after the improvement.

*Corresponding Author

Welly Atikno
E-mail: wellbjbs2@gmail.com

1. INTRODUCTION

Currently, the development of the survey service industry continues to increase [1]. Therefore, the role of independent survey service companies (surveyors) is very important to carry out technical verification by producing valid and accurate data and information [2], [3]. Total Sulfur Analyzer (TS Analyzer) is a laboratory tool in the survey service industry to test the total sulfur content in coal samples. Technically, specifications and use are regulated in the international standards ISO 19579-2006, ASTM D4239-18e1, and GBT 25214-2010. During 2020 in the Coal Laboratory Service Industry, downtime was found based on initial observations. Downtime is a problem in machine availability [4]. Downtime is when the machine/ equipment is not functioning, so it takes time for repair or replacement [5], [6]. High downtime explains that equipment/ machines are not yet effective and efficient [7]. The survey showed that 2 local surveyors and 2 international surveyors had problems with downtime (Fig.1). Downtime is one of the causes of the surveyor's output not reaching the target so that productivity decreases.

Losses caused by downtime are affected by Six Big Losses [8]. Six Big Loses is the cause of equipment/ machines not operating normally [9].

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Six Big Losses that interfere with the performance of machines/ equipment cause losses that are not realized by the company [10].

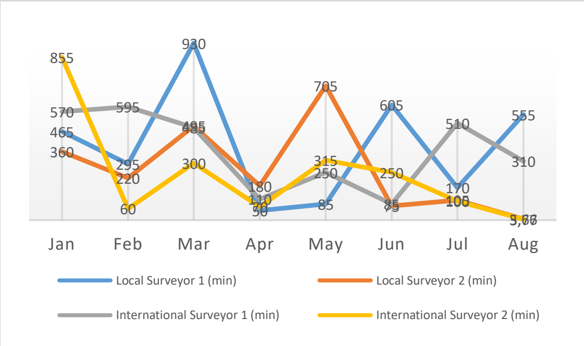

Fig. 1. Downtime survey data

It is necessary to solve production facilities' problems to increase productivity. One of the best ways is to evaluate and improve the effectiveness of the equipment/ machine so that it can be used optimally [11]. Overall Equipment Effectiveness (OEE) is a key factor in measuring the productivity and effectiveness of equipment/ machines [12], [13]. OEE measurement is essential for monitoring how the machine operates and what losses reduce effectiveness so that improvement efforts can be evaluated and adjusted to needs [14], [15] According to Nakajima [16], OEE is a parameter that focuses on the effectiveness of machines/ equipment to measure company productivity. OEE is the most effective action to encourage machine/ equipment improvement [9]. OEE is the ability of the engine to work optimally in the best conditions to produce maximum output and quality [17]. OEE is based on the measurement of three main ratios: the machine's availability, performance, and the machine's quality [7]. According to Nakajima [16], the international standardized OEE value by JIPM is 85%.

Availability is a ratio that describes the utilization of available time for machine/ equipment operation activities [18]. Availability is a comparison of operation time with loading time. Performance is a ratio that describes the ability of the equipment/ machine to produce goods [19]. This ratio is the ideal cycle time multiplied by the number of products produced, both good and defective product. Quality is a comparison that interprets the reliability, capability and performance of equipment to produce products that meet the expected specifications [20]. The OEE value is obtained by multiplying the three main ratios: availability, performance and quality [21].

Meanwhile, to analyze the potential for failure of low OEE values, the Failure Mode and Effect Analysis (FMEA) method can be used. FMEA is a method used to identify all possible failure risks in a design or process [22]. According to Stamatis [23], FMEA is used to determine the priority ranking of problems that will be repaired through the calculation of the Risk Priority Number [24].

Several previous studies support this research by Alfatiyah & Bastuti [25], Purba et al. [26], Saleem et al. [27] and Manjunatha et al. [28]. Research by Rozak et al. [29], implements FMEA and OEE in the manufacturing industry. His research focuses on increasing OEE values in cylinder block machining. Based on the analysis with FMEA, it is known that the priority problem is the damage to the proximity switch and regulator. After improvement, the machine has improved performance. This research has a drawback, namely the cause of the low effectiveness of the engine because the engine components are often damaged. It leads to a lack of regular maintenance carried out by the maintenance team. Research by Agung & Siahaan [30], research in the Chemical Industry proves that the application of Total Productive Maintenance positively increases the OEE value by reducing six big losses. This research has limitations in implementing improvements not involving experts. Research Salem et al. [27] shows that through FMEA it is known that problems that often occur cause machines to experience damage which has an impact on quality degradation. The research has a drawback that the improvements made have not been supported by top management so the expected OEE value has not been achieved. This research focuses on the Coal Laboratory Service Industry which is located in Jakarta. In addition, problem analysis is carried out by involving experts through Focus Group Discussions (FGD). This study aims to measure the effectiveness of the operational performance of the TS Analyzer tool in the laboratory as a whole, find the root cause of the problem and take corrective action. The method used is the integration of FMEA and OEE.

2. RESEARCH METHODS

This study aims to measure the effectiveness of the machine as a whole, analyze the causes of problems that cause the low OEE value and take corrective actions. The low value of OEE on the TS Analyzer will be analyzed with six big losses. Six big losses are losses that the machine explores while operating. These six big losses include breakdown time, set-up & adjustment, idling & minor, reduced speed, rework and scrap. 1) Breakdown losses are an event of engine damage that occurs suddenly or unwanted and causes losses to the company, causing the machine to stop operating and affecting production results. 2) Set-up adjustment losses are caused by machine dandori (change of type/ model) at the beginning of work or when changing over products and performing 5S on machines/ equipment at the end of working time. 3) Idling and Minor Stoppages Losses are losses caused by engine congestion, such as abnormal engine components or dirt sticking to engine spare parts, which cause the engine to stop for a moment. 4) Reduce Speed Losses are losses caused by a decrease in the speed of the engine speed in operations, or the engine does not work optimally. 5) Rework Losses are losses caused by defective products or rework activities that cause loss of production time and can cause material losses. 6) Scrap losses/ reject losses are time and material losses that arise during the time the machine requires to produce new products as expected. Based on these problems, an improvement is needed to overcome them.

This type of research is included in the mixed method, a combination of quantitative and qualitative [31]. Quantitative focus on calculating the OEE value and FMEA analysis. While the qualitative focus on analyzing the factors causing the problem. The research focuses on the TS Analyzer Machine in the Coal Laboratory Service Industry. This study uses primary data, which is obtained through direct observations in the field and Focus Group Discussions (FGD). In addition, secondary data is also used. This data was obtained from company reports such as the number of defective products, downtime and maintenance time. Other secondary data were obtained from articles in journals and institution annual reports. This research uses systematic stages so that the research carried out is directed, structured and not out of target. The stages of the research used can be seen in Fig. 2.

2.1. Pre-study

In this section, the first step is to explain the problems that make the TS Analyzer machine's performance work not optimally so that productivity decreases. A literature review was conducted to understand the methods used in this research. This section describes the TS Analyzer Machine in the Coal Laboratory Service Industry.

2.2. Measurement

In this section, the calculation and measurement of the baseline value of machine availability, machine performance, machine quality and machine OEE. Through this calculation, companies can set a standard OEE value. The target set by the company is for the machine effectiveness to be equal to the international standard of 85%. Mathematically the formula for measuring Availability (A), Performance (P), Quality (Q) and OEE values is as follows:

$$A = \frac{(\text{Loading Time} - \text{Unplanned Downtime})}{\text{Loading Time}} \text{ x } 100\% \quad (1)$$

$$P = \frac{(\text{Idle Run Time x Total Production Part})}{\text{Operating Time}} \text{ x } 100\% \quad (2)$$

$$Q = \frac{(\text{Total Produced Parts} - \text{Total Defect Parts})}{\text{Total Produced Parts}} \text{ x } 100\% \quad (3)$$

$$OEE = A \text{ x } P \text{ x } Q \quad (4)$$

2.3. Analysis

This section analyzes the factors causing the problem, defining the root of the problem through the analysis of six big losses. The Pareto chart determines the priority of the Six Big Losses factors that will be improved. Next, analyze the factors causing the 1E+4M problem using a Fishbone Diagram. This analysis was obtained from the results of the FGD. FMEA method is used to determine the priority of improvement in this case. FMEA analysis considers three factors, Occurrence (O), Severity (S), and Detection (D), to get the highest Risk Priority Number (RPN). Each Severity (S), Occurrence (O) and Detection (D) mode is based on a scale of 1 to 10. In severity, one represents rarely, and 10 represents frequent. In the occurrence level, one indicates insignificant, and 10 indicates dangerous. lastly, in detection, one refers to easily detectable, and 10 describes detection as very impossible [32], [33]. The highest RPN value is a critical point for improvement.

$$RPN = S \text{ x } O \text{ x } D \quad (5)$$

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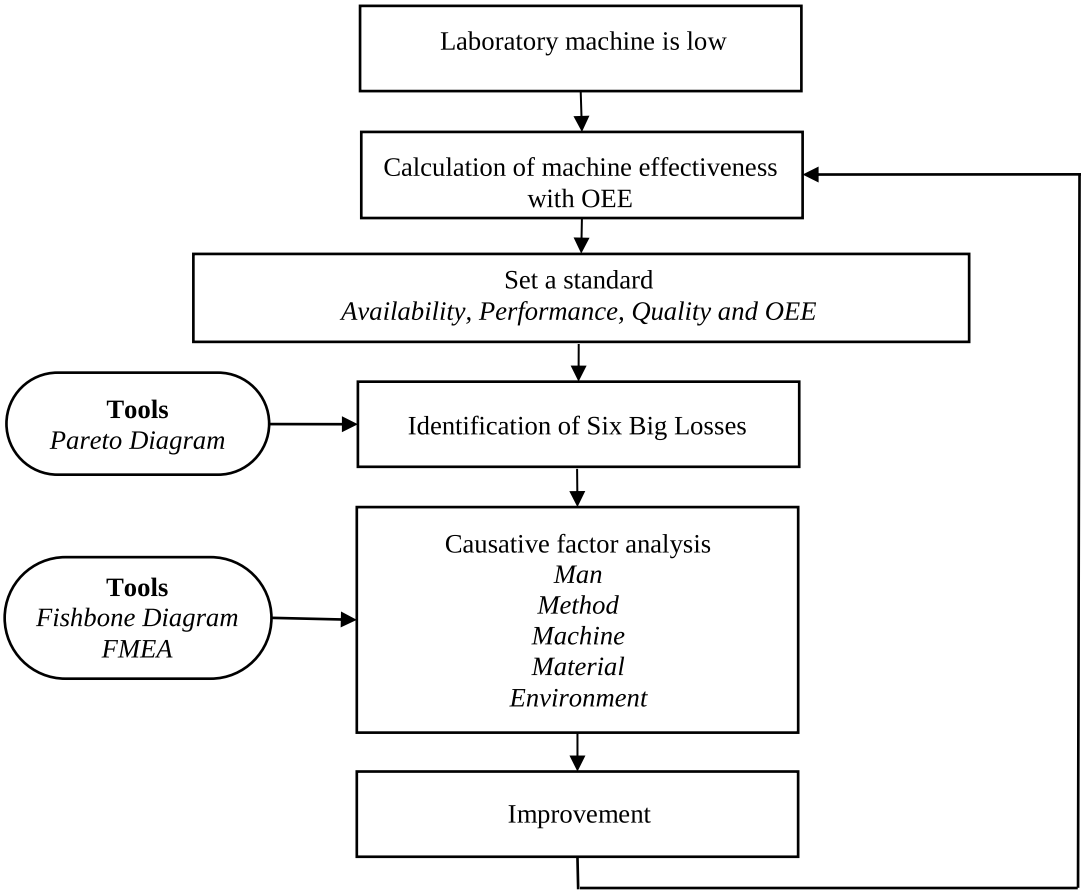

Fig. 2. Study framework

2.4. Implementation

In this section, improvements were made with the experts involved in the FGD. The resulting improvement recommendations will be implemented. Implementation is to apply several recommendations for improvement obtained. To find out the improvement results, measurements and calculations of the OEE value are carried out in the next month.

3. RESULTS AND DISCUSSION

3.1. Data Analysis

3.1.1. *Pre-study*

The first part is to define the problems that occur in the TS Analyzer machine in the Coal Laboratory Service Industry. In 2020, the productivity of the machines was so low that the company could not achieve the target. At this stage, a description of the TS Analyzer engine is also carried out. Total Sulfur Analyzer (TS Analyzer) is a laboratory tool in the Coal Laboratory Service Industry to test the total sulfur content in coal samples. The following essential parts of the TS Analyzer Engine can be seen in Fig. 3.

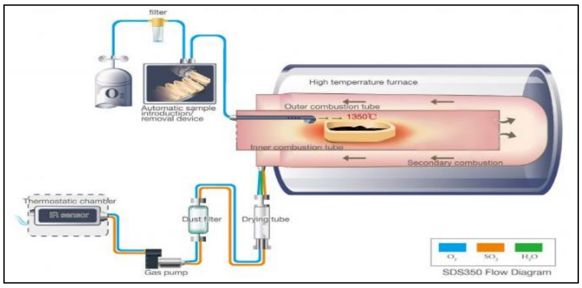

Fig. 3. Main parts of the infrared sulfur analyzer

3.1.2. *Measurement*

This section calculates the OEE value before the repair to determine the company's baseline OEE value. The calculation of the OEE value obtained on the TS Analyzer Machine owned by the company is to be used as company standards. The calculation of the OEE value uses the formula (1), (2), (3), (4).

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Based on the calculation with formula (1), the Availability value is 85.07%. Based on the calculation with formula (2), the performance value is 97.48%. Based on the formula (3) calculation, the quality ratio value is 99.58%. The OEE value is calculated to determine the overall effectiveness of the TS Analyzer machine. Based on the calculation with formula (4), the OEE value is 80.53%.. The value of this calculation is carried out on the January sample.

$$\text{Availability} = \frac{(7{,}780 - 1{,}161)}{7{,}780} \text{ x } 100\% = 85.07\%$$

$$\text{Performance} = \frac{(6 \text{ x } 480)}{3{,}030} \text{ x } 100\% = 95.05\%$$

$$\text{Quality} = \frac{(480 - 2)}{480} \text{ x } 100\% = 99.58\%$$

OEE = 85.07% x 95.05% x 99.58% = 80.53%

The recapitulation of the OEE value for January to December 2020 can be seen in Table 2. The OEE value is still low because it is below the international OEE value standard. Therefore, it is necessary to identify the Six Big Losses to find out the source of the problem at the low OEE value.

3.1.3. *Analysis*

Six Big Losses analysis was conducted to find the source of the problems that caused the low OEE value. Six Big Losses are based on company data from January to December 2020. The highest downtime problem can be obtained, occurring at a breakdown loss of 63.5% (Fig. 4). The losses caused by reworking and scraping the TS Analyzer machine are minor and even non-existent. Based on the company's report, breakdown loss is caused by internal damage and heating, so it becomes a critical point for repairs. The interior and heaters during 2020 were damaged 5-6 times. This section identifies the leading cause of the two problems that have been identified through Environment Method, Material, Machine, Man, Environment (1E+4M). Analysis and identification of the causes of the problem were carried out through FGD with experts. The expert involved in the FGD includes a senior technician from a sole agent with 21 years of experience, a head of a branch with 18 years of experience, a laboratory manager with 15 years of experience, quality assurance with 25 years of experience, laboratory supervisor with eight years of experience, analyst and maintenance officer from company with 5 years of experience.

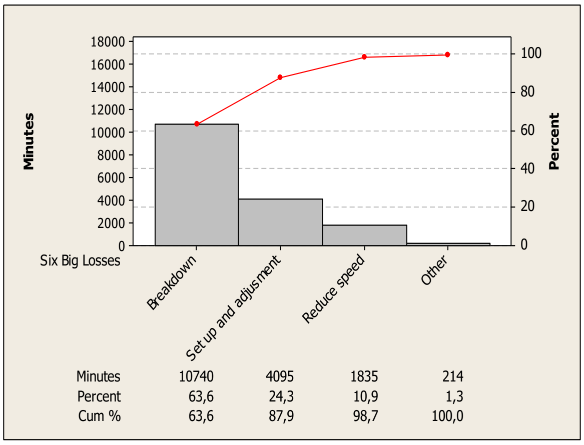

Fig. 4. Pareto diagram of six big losses

Five failure factors that cause the inner-outer to be damaged quickly are humans, methods, materials, machines and the environment. The human factor is caused by a lack of knowledge, low machine skills, and an uneven workload. The method factor is caused by the absence of SOPs for disabling the machine and improperly changing components. The material factor is caused by the specification of O2 gas that is not in accordance with regulations, and the quality of spare parts is not good. The machine factor is caused by unstable electric current, overheating and unstable temperature changes. The environmental factors are lack of cleanliness in the work environment and the room temperature being too humid.

Five failure factors in silicon carbons are humans, methods, materials, machines and the environment. The human factor is low operator skills and wrong assignments. The method factor is caused by improper lubrication and no machine maintenance schedule. The lack of availability of parts causes the material factor, and the quality of spare parts is not good. The machine factor is caused by the machine's physical condition, which is old, and there is no reset process. Environmental factors are caused by high air pressure and room temperature being too humid.

After the causative factors have been identified, determining the priority of the problem and improvement in the next stage is carried out using the FMEA method through the calculation of the RPN. RPN calculation is done by scoring by experts. The FMEA results shown in this section are priority rankings only. Table 1 shows the analysis and results of FMEA on the silicon-carbon tube and inner-outer tube problems.

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Table 1. FMEA analysis of silicon-carbon (heating) and inner outer

Factor	Potential Failure Mode	Sev	Potential Failure Effects	Occ	Potential Cause of Failure	Det	RPN	Current Design Control	Improvement
Silicon carbon tube/ Heating	Overheating	7	The heating element, inner, and outer tube quickly break and cracked	6	The installation thermocouple is not correct	8	336	Function	Improvement of SOP and training for employees
	Unstable electric current	7	The heating element quickly break, and the controller is broken	8	Unexpected power change	6	336	Function	Installation Uninterruptible Power Supply
	Skill Operator is lack	8	Fault in maintenance	7	Lack of training	6	336	Function	Training
The inner and outer tube	Temperature change is fast and unstable	7	The eating element, inner and outer tubes quickly break and cracked	7	The transition of electric current to the generator	7	343	Visual	Installation UPS
	Oxygen gas specifications are not precise	7	Inner outer is break	7	Oxygen gas contains moisture	7	343	Visual	Addition of air dryer (Silica Gel)
	The way to shut down the machine is not correct	7	The heating element, inner, and outer tube quickly break and cracked	7	The difference in temperature settings by each operator	7	343	Visual	Improvement of SOP and training for employees

3.1.4. *Implementation*

Improvements were made based on the highest RPN values, summarized in Table 1. Improvements were obtained from the advice of the experts through FGD with the experts. The recommended improvement points are then implemented for improvement. Here are some fixes based on RPN ranking.

There are three potential failures caused by improper use/operation of the TS Analyzer machine. Based on the FGD, standardization was carried out by providing attention points and the right way of operation. Improvements to the Standard Operation Procedure (SOP) are aimed at Work Instruction (WI) with the identity of IK-LAB.1-10-05-01. WI Edition 1 2021 – revision 1. Improvements to SOP and training are carried out to give machine operators a particular under-standing of how to operate the TS Analyzer Machine. The training and socialization for the employee can be seen in Fig. 5.

There are two potential failures caused by the unstable electric current so that the machine gets a high voltage which impacts overheating. Repairs were made by installing Uninterruptible Power Supply (UPS) on the TS Analyzer machine. The purpose of the installation is so that the heating element does not break quickly and prevents electric current spikes. The UPS installation can be seen in Fig. 6.

Fig. 5. Training and socialization for employee

The third improvement was carried out on the inner-outer of the TS Analyzer machine. The factor causing this failure was caused by oxygen gas-containing moisture, so the temperature setting was not following the regulation. Based on the FGD, improvements were obtained by installing Silicon Gel to be a stabilizer or air dryer. The following implementation of improvements can be seen in Fig. 7.

Fig. 6. Improvement with UPS installation

Fig. 7. Installation of silicon gel/stabilizer

After improving the potential causes of failure, the OEE value is carried out by analysis and calculation to determine the post-improvement condition. This value continues to refer to international standards as standards/ KPIs. This calculation uses the formula (1) (2) (3), and (4). The following recapitulation of improvements can be seen in Table 2.

The OEE value on the TS Analyzer machine has increased. The average OEE score increased from 83.91% to 95.18%. The company declares the OEE value after improvement as the latest standard of machine effectiveness. Most OEE in the laboratory has met the world-class standard above 85%, and even the lowest OEE value of 83.92% is close to the world-class standard. It is strongly influenced by the quality management system implemented in all coal testing laboratories registered with the Ministry of Energy & Human Resources and the Ministry of Trade. The company has implemented a quality management system by obtaining the ISO 17025 Accreditation. The contents of the ISO 17025 certification are each test parameter must strictly follow international standards, such as American Society Test and Materials (ASTM), International Standard Organization (ISO), British Standard (BS), Australian Standard (AS), Guobiao (GB), or Japanese Industrial Standard (JIS). The application of OEE can be used to complete the control system to monitor the effectiveness of equipment in the laboratory.

Table 2. Recapitulation of OEE values before and after improvement

Month		Availability	Performance	Quality	OEE
Before 2020	Jan	85.07%	95.05%	99.58%	80.53%
	Feb	92.75%	94.90%	100.00%	88.01%
	Mar	92.11%	95.92%	99.49%	87.90%
	Apr	84.79%	96.68%	99.72%	81.74%
	May	77.60%	97.63%	99.42%	75.32%
	Jun	100.00%	92.54%	99.68%	92.24%
	Jul	87.74%	95.34%	100.00%	83.64%
	Aug	91.73%	94.00%	99.74%	86.01%
	Sep	77.46%	97.02%	99.75%	74.96%
	Oct	82.08%	96.92%	100.00%	79.55%
	Nov	87.22%	96.44%	100.00%	84.11%
	Dec	93.61%	96.85%	99.74%	90.42%
	Average 2020	87.68%	95.93%	99.76%	83.91%
Improvement (2021)	Jan	92.70%	97.63%	100.00%	90.50%
	Feb	100.00%	97.27%	99.33%	96.61%
After 2021	Mar	100.00%	97.73%	99.63%	97.36%
	Apr	100.00%	96.11%	100.00%	96.11%
	May	100.00%	96.24%	99.06%	95.34%
	Average 2021	98.54%	96.99%	99.60%	95.18%

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3.2. Research Implication

Based on the improvements made to the TS Analyzer engine, an increase in the OEE value was obtained. The results of this improvement can directly increase the productivity and effectiveness of the TS Analyzer machine so that it impacts company profits. This research has proven that the downtime problem on the TS Analyzer Engine has been successfully resolved. Downtime decreased from 14,835 minutes to 1,234 minutes. The Coal Laboratory Services Industry always makes continuous improvements to improve machine performance, effectiveness and reliability as a KPI for the company's success. Contribution from top management is needed to support continuous improvement.

3.3. Comparison with Previous Research

Improving the effectiveness and productivity of the TS Analyzer machine with the FMEA and OEE integration methods can increase the OEE value. Based on the results of these improvements, the company could benefit from both productivity and financial terms. The company can eliminate maintenance, labour, and material costs through this improvement. The findings and results of this research follow Saifuddin et al. [34] that the OEE and FMEA methods can increase the machine's effectiveness. According to research by Agung & Siahaan [30], to increase machine effectiveness, the implementation of TPM pillars is carried out to become an opportunity for further research. Research by Muthalib et al. [35] shows that machine maintenance in the cement industry requires the involvement of all personnel, from operators to top management. Research by Mahto, and Kuma [36] has a weakness in problem analysis; namely, all possible fundamental failures on the machine are not all identified. It is because the failure identification is carried out with the assumption that the failure of basic loss (root cause) begins with a top event. However, there is no guarantee that all the initial events have been identified.

Meanwhile in this study, the analysis of the causes of the problem used a sensitivity study conducted through FGD with expert judgment. This result provides the best decision because it can be verified directly by experts in their field. This analysis makes it an advantage in this study compared to previous studies. Based on the results of this study, corrective actions given to operators related to training provide positive opportunities in the future to carry out autonomous maintenance. Indirectly, this action provides knowledge to the operator and changes the mindset of the operator to take preventive action earlier on the TS Analyzer machine. This research does not involve a cost analysis on the TZ Analyzer machine improvement project so it becomes a limitation because it can't know the cost savings received by the company before and after improvement.

4. CONCLUSION

Based on the previous section analysis, the cause of the low effectiveness failure can be known with the highest RPN. It is caused by the operator who does not comply with the SOP in operating the machine, the unstable temperature of the engine and the unstable electric current due to the delay in switching electricity from Perusahaan Listrik Negara (PLN) to the generator. Based on the FGD by the experts, the repairs were carried out by making improvements to the SOP, adding UPS to the TS Analyzer Machine and adding Silicone Gel as a stabilizer to regulate the air temperature. This research has shown that the TS analyzer engine has increased the OEE value. The average increase in the OEE value. This result satisfies the Coal Laboratory Service Management because it can reduce the high downtime. The limitation of this research is that it does not analyze and apply automation-based technology. The future research is to carry out overall machine maintenance and improvement by applying predictive maintenance that refers to Technology 4.0, such as installing sensors for early detection of damage to machines.

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