Evaluation of Effectiveness and Cost of Machine Losses using Overall Equipment Effectiveness (OEE) and Overall Equipment Cost Loss (OECL) Methods, a case study on Toshiba CNC Machine

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Abstract. In a manufacturing company, the machine is one of the most important elements in their production process because machine failure can stop the production process. Therefore, the initial step to minimizing losses caused by machine failure can be done by evaluating the machine condition. Evaluation of machine performance is carried out by measuring the effectiveness of the machine with the Overall Equipment Effectiveness (OEE) method. Based on the calculation result, the OEE value of the machine is 68.63% and this value still under the Japanese Institute of Plant Maintenance standard. Six big losses analysis is performed to determine the biggest loss that affects the effectiveness of the machine. The result of six big losses calculation shows that the most influential factor for the low OEE value of the machine is Reduced Speed Loss (39.12%). Causal analysis with a fishbone diagram is done to find out the causes of the highly reduced speed loss. To calculate the equipment cost loss use the Overall Equipment Cost Loss (OECL) methods. The total of the overall equipment cost loss is IDR 849,839,947.53.

Keywords: OEE, OECL, six big losses, fishbone diagram, machine performance.

1. Introduction

Machine is one of the important elements to support the production process in a manufacturing company. Machine failure that occurs suddenly can disrupt the production process. Based on [1] machine maintenance is inseparable from the problems of efficiency and effectiveness of machinery. Therefore, actions are needed to prevent or overcome the problem of machine downtime. OEE is a quantitative metric used in the manufacturing industry for controlling and monitoring the productivity of production equipment and as an indicator of process drivers and performance improvement [2]. According to Nakajima, OEE is based on three performance aspects: availability rate (A), performance efficiency (P) and Quality rate (Q) [3]. From [4] OEE measurements were carried out on 50 units of machinery in the company that manufactures tractors. OEE values indicate the need to improve machine effectiveness. Then the implementation of Total Productive Maintenance and within 5 years the value of OEE has increased. Based on [3] OEE is also used to help identify issues of availability and efficiency in wire mesh producing companies. This research was conducted at X company, which produces industrial equipment. High demand causes the production process to be carried out for 24 hours and causes machine failure, which disrupts the production process. Evaluations of machine performance is done by
measuring the effectiveness of the machine with the OEE method. Then, six big losses identification carried out to know the highest losses from the machine. The highest loss factor will be analyzed with a causal diagram to find out the causes. Machine failures results a loss costs, then the OECL method used to calculate it. This research will focus on Toshiba CNC machine which used to produce arm excavators because it has the highest level of failures.

2. Methods

In conducting this research, several steps must be taken as data collection and then calculation to evaluate the state of the machine. Calculations and analysis are carried out in the following steps.

2.1. Overall Equipment Effectiveness

OEE is used to measure the effectiveness of several equipments or systems in which the measurement process is related to several considerations [5]. According [6] OEE calculation formula is:

\[
OEE = \text{Availability} \times \text{Performance} \times \text{Quality}
\]  

2.1.1. Availability. Availability calculation aims to be able to find out how much the level of machine availability. According to [5] the availability value can be calculated by the following formula:

\[
\text{Availability (A)} = \frac{\text{loading time} - \text{downtime}}{\text{loading time}} \times 100\%
\]  

2.1.2. Performance Efficiency. Performance efficiency is the ratio of the total products produced to the total products that could have been produced [6]. Performance efficiency can be calculated by the following formula [5]:

\[
\text{Performance Efficiency (P)} = \frac{\text{processed amount} \times \text{theoretical cycle time}}{\text{operation time}} \times 100\%
\]  

2.1.3. Rate of Quality. The Rate of Quality shows how much success a machine produces in a product that is not defective. According to [5] the value of the rate of quality can be calculated by the following formula:

\[
\text{Quality (Q)} = \frac{\text{processed amount} - \text{number of defect}}{\text{processed amount}} \times 100\%
\]  

2.2. Six Big Losses

Six big losses are the six losses that affect the effectiveness of the equipment. The types of losses are as follows [1].

2.2.1. Equipment Failures. Equipment Failure is a loss caused by failure of equipments so it takes time to repair. According to [1] equipment failure loss can be calculated by the following formula:

\[
\text{Equipment Failure} = \frac{\text{total breakdown time}}{\text{loading time}} \times 100\%
\]  

2.2.2. Setup and Adjustment. Setup and Adjustment is a loss caused by setup and adjustments such as shifts turnover, changes in operations and products. Setup and adjustment loss can be calculated by the following formula [1]:

\[
\text{Setup and Adjustment} = \frac{\text{total setup and adjustment}}{\text{loading time}} \times 100\%
\]
2.2.3. **Idling and Minor Stoppages.** Idling and Minor Stoppages are losses caused by the equipment doesn’t work for a while due to sensor failure, machine error, and machine idle. This losses can calculate by the following formula [1]:

\[
\text{Idling and Minor Stoppages} = \frac{\text{nonproductive time}}{\text{loading time}} \times 100\% 
\] (7)

2.2.4. **Reduced Speed Losses.** Reduced Speed is a loss caused by a decrease in production speed. According to [1] the reduced speed value can be calculated by the following formula:

\[
\text{Reduced Speed} = \left(\frac{\text{operation time} - (\text{theoretical cycle time} \times \text{processed amount})}{\text{loading time}}\right) \times 100\% 
\] (8)

2.2.5. **Defect Losses.** Defect Loss is a loss caused by a defect in the product produced. According to [1] the value of defect loss can be calculated by the following formula:

\[
\text{Defect Loss} = \left(\frac{\text{total product reject} \times \text{theoretical cycle time}}{\text{loading time}}\right) \times 100\% 
\] (9)

2.2.6. **Reduced Yield.** Reduced Yield is a loss caused by a defective product at the beginning of production time where the machine condition is not stable yet, calculated with following formula [1].

\[
\text{Reduced Yield} = \left(\frac{\text{theoretical cycle time} \times \text{reject production}}{\text{loading time}}\right) \times 100\% 
\] (10)

2.3. **Pareto Diagram**

Pareto diagram is a diagram that interprets data classification based on the highest order to the lowest order so that the main problem can be identified. The advantage of the Pareto diagram is it can show the most vital problem [7].

2.4. **Fishbone Diagram**

Cause and Effect Diagrams (Fishbone Diagrams) developed by Dr. Kaoru Ishikawa in 1943 and often called the Ishikawa Diagram. Cause and Effect Diagrams is a diagram that resembles fish bones where this diagram can show the relationship between the causes and effects of an event [7].

2.5. **Overall Equipment Cost Loss**

The OECL method was developed to calculate the overall cost of losses caused by equipment. The cost of loss is calculated using the same three main elements of the OEE method, namely availability, performance, and quality rate. OECL calculation is as follows [8].

\[
\text{OECL} = \text{Availability Losses} + \text{Performance Losses} + \text{Quality Losses} 
\] (11)

2.5.1. **Availability Losses.** To find out the cost of losses resulting from availability can be calculated by the following formula [9]:

\[
\text{AL} = \text{OL}_A + \text{PCL}_A 
\] (12)

Where,

\[
\text{OL}_A = \text{LT} \times \text{M}_{\text{cap}} \times \text{PPU} 
\] (13)

\[
\text{LT} = \text{breakdown time} + \text{set up and adjustment time} 
\] (14)

\[
\text{PCL}_A = \sum \frac{\text{LT} \times \text{E}_i}{\text{Loading time}} 
\] (15)

where \(\text{OL}_A\) is opportunity loss for availability rate element (Rp), LT is loss time (hour), \(\text{M}_{\text{cap}}\) is maximum capacity (units/hour), PPU is profit per unit (IDR/unit), \(\text{PCL}_A\) is production cost loss for
availability (IDR), EP_A expense (IDR/month) of production cost i for availability rate element according to Table I [9].

| OEE elements          | A | P | Reject (Qrej) | Rework(Qrew) |
|-----------------------|---|---|--------------|--------------|
| Opportunity cost      | ✓ | ✓ | ✓            | x            |
| Direct material cost  | x | x | ✓            | x            |
| Direct labour cost    | ✓ | ✓ | ✓            | ✓            |
| Indirect material cost| x | x | ✓            | ✓            |
| Indirect labour cost  | ✓ | ✓ | ✓            | ✓            |
| Facility cost         | x | ✓ | ✓            | ✓            |
| Depreciation cost     | ✓ | ✓ | ✓            | ✓            |
| Maintenance cost      | ✓ | ✓ | ✓            | ✓            |
| Renting cost          | ✓ | ✓ | ✓            | ✓            |
| Insurance cost        | ✓ | ✓ | ✓            | ✓            |
| Welfare cost          | ✓ | ✓ | ✓            | ✓            |
| Rework cost           | x | x | x            | ✓            |

2.5.2. Performance Losses. Performance efficiency losses is calculated to find out the loss caused by the amount of production is under the maximum capacity of the machine. The number of costs resulting from performance loss can be calculated using the following formula [9]:

\[
PL = OL_P + PC_{L_P}
\]  

Where,

\[
OL_P = LU \times PPU
\]  

\[
LU = \text{maximum capacity} - \text{actual production}
\]  

\[
PC_{L_P} = \sum \left[ \frac{LU}{M_{\text{cap}}} \times EP_{iP} \right]
\]

where OL_P, opportunity loss for performance efficiency element (IDR), LU, loss unit (units); PC_{L_P}, production cost loss for performance efficiency element (IDR), and EP_{iP}, expense (IDR/month) of production cost i for performance efficiency according to Table 1.

2.5.3. Quality Losses. From [9] Quality losses are identified from two types of losses namely the reject losses and the rework losses. Therefore, quality losses can be calculated as follows:

\[
QL = \text{RejL} + \text{RewL}
\]  

Reject loss is a losses that caused by products that not comply with specifications. Losses due to rejects can be calculated by the formula:

\[
\text{RejL} = OL_{Q-rej} + DML_{Q-rej} + PC_{LQ-rej}
\]

Where,

\[
OL_{Q-rej} = \text{Rej} \times PPU
\]

\[
DML_{Q-rej} = \text{Rej} \times EP_{\text{DM}}
\]

\[
PC_{LQ-rej} = \sum \left[ \frac{\text{Rej}}{M_{\text{cap}}} \times EP_{iQ-rej} \right]
\]

where OL_{Q-rej}, opportunity loss for quality rate reject sub element (IDR), Rej, number of rejects (units); DML_{Q-rej}, direct material cost loss for quality rate reject sub element (IDR), EP_{DM}, expense of direct material cost (IDR/unit), PC_{LQ-rej}, production cost loss for quality rate reject sub element (IDR) except direct material cost loss, and EP_{iQ-rej}, expense (IDR/month) of production cost i for quality rate reject (Q_{rej}) sub element except direct material cost loss according to Table 1.
While rework is a product that is not according to specifications but can be fixed. The calculation of rework loss can be written as follows:

\[
\text{RewL} = \text{PCL}_{Q-\text{rew}} + \text{RwkL}_{Q-\text{rew}}
\]

(25)

Where,

\[
\text{PCL}_{Q-\text{rew}} = \sum \left[ \frac{\text{Rew} \times \text{EP}_{iQ-\text{rew}}}{\text{M}_{\text{cap}} \times \text{Net operating time}} \right]
\]

(26)

\[
\text{RwkL}_{Q-\text{rew}} = \text{Rew} \times \text{EP}_{\text{rew}}
\]

(27)

where \( \text{Rew} \), number of reworks (units); \( \text{PCL}_{Q-\text{rew}} \), production cost loss for quality rate rework sub element (IDR) except direct material cost loss, \( \text{EP}_{iQ-\text{rew}} \), expense (IDR/month) of production cost \( i \) for quality rate rework (\( Q_{\text{rew}} \)) sub element according to Table 1, except rework costs, \( \text{RewL} \), rework loss (IDR), and \( \text{EP}_{\text{rew}} \), expense of rework (IDR/unit).

3. Result and Discussion

3.1. Calculation of Overall Equipment Effectiveness

The OEE calculation of the Toshiba CNC machine is based on the breakdown and production data in 2019. The OEE calculation result can be seen in Table 2.

| Month | A       | P       | Q       | OEE (%) |
|-------|---------|---------|---------|---------|
| 1     | 90.59%  | 80.36%  | 100.00% | 72.80%  |
| 2     | 89.81%  | 82.54%  | 100.00% | 74.13%  |
| 3     | 88.37%  | 82.62%  | 100.00% | 73.01%  |
| 4     | 90.58%  | 86.79%  | 100.00% | 78.62%  |
| 5     | 88.73%  | 62.24%  | 100.00% | 55.22%  |
| 6     | 89.56%  | 77.25%  | 100.00% | 69.19%  |
| 7     | 89.63%  | 77.45%  | 100.00% | 69.42%  |
| 8     | 89.16%  | 80.48%  | 100.00% | 71.76%  |
| 9     | 90.17%  | 87.19%  | 100.00% | 78.62%  |
| 10    | 85.81%  | 83.16%  | 100.00% | 71.35%  |
| 11    | 88.10%  | 68.59%  | 100.00% | 60.43%  |
| 12    | 66.61%  | 75.08%  | 100.00% | 50.01%  |
| Average | 87.26%  | 78.64%  | 100.00% | 68.63%  |

OEE calculations are carried out from January–December 2019 by calculating the machine’s Availability, Performance and Rate of Quality values. Based on calculations, the average OEE value of the Toshiba CNC machine is 68.63%. From the OEE values obtained in Table 3, an analysis of whether the OEE value of the Toshiba CNC machine meets the Japan Institute of Plant Maintenance standards.

| OEE Factor         | Calculation Result | JIPM Standard | Standard Fulfilment |
|--------------------|--------------------|---------------|---------------------|
| Availability       | 87.26%             | 90%           | NO                  |
| Performance Efficiency | 78.64%         | 95%           | NO                  |
| Rate of Quality    | 100.00%            | 99%           | YES                 |
| OEE                | 68.63%             | 85%           | NO                  |

Table 3. Fulfillment OEE of Toshiba CNC Machine with JIPM Standard
In the Table 3, it is known that the Availability and Performance Efficiency values do not meet the JIPM standard. The reason for the low availability is due to the high machine downtime. Downtime can be caused by sudden damage to the machine and a long setup and adjustment time. The low-Performance Efficiency value is caused by the actual production time not as expected. The Rate of Quality meets the standards because in 2019 production no defective products were found. The average OEE value in 2019 is 68.63% and this value does not comply with the JIPM standard, so the action is needed to increase the low OEE value of the Toshiba CNC machine.

3.2. Calculation of Six Big Losses
After calculating OEE, the next calculation of six big losses is performed shown on Table 4.

| No | Six Big Losses                  | Losses Percentage (%) | Total Losses Percentage (%) |
|----|--------------------------------|-----------------------|----------------------------|
| 1  | Reduced Speed Loss             | 18.55                 | 39.12                      |
| 2  | Idling and Minor Stoppages     | 13.21                 | 27.86                      |
| 3  | Equipment Failures             | 3.32                  | 7.00                       |
| 4  | Setup and Adjustment           | 9.42                  | 19.86                      |
| 5  | Reduced Yield                  | 2.92                  | 6.16                       |
| 6  | Defect Loss                    | 0.00                  | 0.00                       |
|    | Total                          | 47.42                 | 100.00                     |

According to Table 4, it can be seen that the percentage of the six big losses on a Toshiba CNC machine. The biggest factors that caused losses were Reduced Speed Loss 18.55% or 39.12% from total losses percentage, Idling and Minor Stoppages 13.21% or 27.86% from total losses percentage and Setup and Adjustment 9.42% or 19.86% from total losses percentage. Six big losses greatly affect the machine's OEE value so action must be taken to reduce the six big losses on the machine.

3.3. Analysis of Pareto Chart
The Pareto Chart will represent the six big losses data in the highest to lowest order, so that the main problem can be identified.

![Pareto Chart of Six Big Losses](image)

**Figure 1.** Pareto Chart of Six Big Losses from Toshiba CNC Machine
From Figure 1 it can be seen that the six big losses factor with the highest percentage is Reduced Speed 39.12% from all total losses. In pareto theory, 80% of the problems are caused by 20% of the causes. By dealing with 20% of the problems can solve other problems and effectiveness will increase. Then it is necessary to take action to overcome the problem of the high value of reduced speed loss on the CNC machine.

3.4. Analysis of Fishbone Diagram

To identify the cause of the highly reduced speed based on the calculation of six big losses, an analysis was carried out using a fishbone diagram.

![Fishbone Diagram](image)

Figure 2. Cause Effect Analysis of Reduced Speed Loss Using Fishbone Diagram

Figure 2 shows the causal analysis of the reduced speed loss in the Toshiba CNC machine. The analysis was carried out on four factors namely man, machine, method, and material. In the man factor, operators are often not good at using machines and maintain machine cleanliness due to the lack of operator knowledge. From the machine factor, the use of the machine is almost 24 hours in a day and the old of the machine age. Methods also affect the reduced speed loss, when the production process of the machine is set many times with different speeds, operator skills are needed in the process of setting to avoid failure. Material that is too hard can also cause the machine to work harder when processing material and can cause reduced speed on the machine.

3.5. Calculation of Overall Equipment Cost Loss

In addition to measuring the OEE value on the machine, overall equipment cost loss calculation is also performed. Losses are calculated from three factors which are the same as OEE namely availability, performance and quality. Table 4 is an OECL calculation.

| Availability Losses | Performance Losses | Quality Losses | Total       |
|---------------------|--------------------|---------------|-------------|
| IDR 329,182,951.22  | IDR 510,529,680.55 | IDR 10,127,315.77 | IDR 849,839,947.53 |

The OECL calculation is done using the data of the arm excavator production on the Toshiba CNC machine in 2019. In Table 4 the OECL value obtained on the Toshiba CNC machine is IDR 849,839,947.53. The total loss was obtained from Availability Losses of IDR 329,182,951.22, Performance Losses of IDR 510,529,680.55 and Quality Losses of IDR 10,127,315.77.
4. Conclusion
Based on research that has been carried out on Toshiba OEE CNC machines, the following conclusions are obtained:

1. In 2019, the Toshiba CNC machine has an OEE value of 68.63%, which is this value under the standard of JIPM.
2. From total losses of six big losses, factors that contributed significantly to the low OEE value were 39.12% reduced speed loss, 27.86% idling and minor stoppages and 19.86% setup and adjustment.
3. Based on the pareto chart theory, by dealing with 20% of the problems can solve other problems, so is necessary to take action to overcome the problem of the high value of reduced speed loss.
4. From causal analysis carried out for the high reduced speed losses using a fishbone diagram, the causes are: man, machine, method and material. The main cause of the reduced speed loss is because the operator is not good at using and cleaning the machine, the machine setting technique, the machine age is old and used almost 24 hours a day. It is necessary to increase operator skills and autonomous maintenance.
5. Based on the calculation, the total OECL by the company is IDR 849,839,947.53.
6. For further research should be conducted to improve the effectiveness of the machine.

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