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Analysis of the Overall Equipment Effectiveness (OEE) to Minimize Six Big Losses of Pulp Machine: A Case Study in Pulp and Paper Industries

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Abstract. Overall Equipment Effectiveness (OEE) is a method of measuring the usage effectiveness of the equipment. This method is known as an application of a Total Productive Maintenance (TPM) program. The ability to clearly identify the source of problem and it causal factors is the main advantage of this method since the improvement effort becomes focused. Pulp and Paper Industries is one of the manufacturing companies that produce dissolving pulp products (rayon fibre). Based on data from the fibre line department, for the period of January - July 2016, the production process of rayon fibre often experienced constraints due to the high downtime and losses in the pulp machine. This is caused of using production process equipment that had not operate optimally. It is important to find out the source of the problem and its causal factors before the company makes any improvement effort. This study aims to identify equipment losses and measure the achievement of OEE values in the pulp machine. The measurement result shows that the average of the effectiveness of pulp machine for the period of January - July 2016 was 74.01% and based on Japan Institute of Plant Maintenance (JIPM) the value has not reached the standard that is > 85%, however, there is still possibility for improvement. One of the loss factors that give the most significant effect on the overall equipment effectiveness of the pulp machine is the reducing speed, where it comprises 27.6% of the loss. One way to minimize the loss is by maintaining the actual speed of operation and maintaining wear on each pulp machine roll.

1. Introduction

The increased competition in business requires the leaders of manufacturing companies to oversee the performance of every business function, including the production and maintenance sections in order to achieve their competitive advantage. With increasing global competition, executive attention has shifted from increased efficiency through adjustment of economies of scale and internal specialization, to the fulfilment of market conditions in terms of flexibility, delivery performance and quality. Increased productivity is very important for companies to gain success in their business. One example of increased productivity is to evaluate the performance of production facilities at the company [1]. In general, the problems of production facilities that cause it to be interrupted or stopped entirely can be categorized into three, namely human, machinery and environment factor. One way to solve the problems of production facilities and to increase productivity is the need for intensive evaluation and maintenance of production machinery [2].

In the 1980s, Nakajima (1988) launched the total productive maintenance (TPM), which led to a metric called Overall Equipment Effectiveness (OEE). It is commonly used in industries as a tool to identify and measure the productivity of machines. Made up of three elements called performance rate, availability rate and quality rate, it is a performance measurement tool providing an updated status of any production that has the least details in the calculation. Furthermore, this tool can identify potential losses and suggest actions to minimize their occurrence. This measurement is possible to be conducted on machines, men, as well as material which leads to better performance in producing the products. OEE have some advantages as follows:

1. OEE can reduce equipment downtime and maintenance costs which in turn will contribute to a better management of the equipment cycle time.
2. OEE can increase labour efficiency and at the same time increases the productivity due to improvement in operation visibility since there are empowerment for the operator.
3. OEE can enhance productivity since it can possibility identify the bottlenecks.
4. Due to less rework of products, reduces scraps can contribute to improves quality rate.

TPM and OEE have their main role in minimizing the six big losses which are regarded as the main causes of efficiency loss. The relationship between the losses and the effectiveness in TPM is referred to both the quality of the product and the equipment availability. Face losses may be experienced at any operating time and these losses may be visible such as scrap, changeovers and breakdowns or can be invisible like the slow running, the adjustment that is conducted regularly to keep the production within tolerance. In terms of machine maintenance, there are three things that every company should avoid, namely downtime, speed losses and defect or quality losses [1][3].

According to Nakajima, (1988), there are 6 equipment losses that cause low performance of the equipment. The six losses are called six big losses consisting of: (1) equipment failure, (2) setup and adjustment, (3) idle and minor stoppages, (4) reduced speed, (5) process defect; and (6) low yield. According to him, equipment failure, and setup and adjustment are categorized as downtime losses, reducing availability; idle and minor stoppages, and reduced speed is categorized as speed losses, thus reducing performance. Finally, process defect and reduced yields are considered as defect losses generated from low quality.

1.1. Downtime Losses as a function of Availability

It is found out that if the output is zero and the system produces nothing, or when the machine works, but it does not produced any products during the examination period then it is called downtime losses, and it primarily because of two factors namely a breakdown loss, which refers to parts failure where they cannot work properly any longer and repair or replacement is required and the losses are measured by the time needed for labour or parts for fixing the problem; and setup and adjustment time which are related to the changes in the various operating conditions, e.g. the start of production or the start of the different shifts, changes in products and condition of the operation. Equipment changeovers, exchange of dies, jigs and tools are the primary examples of this kind of losses and these losses consist of setup, start-up and adjustment down times [1].

1.2. Speed Losses as a function of Performance

Speed losses occur when the output is smaller than reference speed output and there is no inspection whether the output complies with quality specification standard. Speed loss can take two forms: Minor stoppage – it can happen due to machine halting, jamming, and idling. This is considered by many as the breakdowns as it is one important factor that needs to be foreseen [4]. Speed losses occur because of the reduction in the speed of the equipment or in the other words, the machine does not work at its theoretical maximum speed. To deal with regular occurrence of quality defect and minor stoppage problems, the machine can be run at low speed. It is measured by comparing the theoretical to actual working load [1] [5]

1.3. Defect or quality losses as a function of Quality

When the output produced does not conform to the specification, thus it is considered as a quality loss. This might cause a rework for quality defects that happen during the regular cycle of production. Since the products do not meet the standard, so that rework is conducted to remove the defects. Labour is required to do the rework which means that the company should spend some cost while the materials that have become scraps is also disadvantage for the company. The extent of these losses is calculated by the ratio of the quality products to the total production. Second is yield losses which result in wasted raw materials .The yield losses are categorized into two groups -the raw materials losses, which are related to the product design, manufacturing method, etc, and adjustment losses refer to quality defects of the products produced at the beginning of the production, changeovers, etc. [1].

Nowadays, the problems faced regarding repair or maintenance by most of the manufacturers are due to the absence or ineffectiveness of systems or methods that can measure performance of existing equipment and can provide solutions to the source of problems encountered. For that reason, the selection of performance measurement method is very important for the companies in achieving their goals. One method to measure the performance measurement that is widely used by companies, especially by Japanese companies that is able to overcome equipment problems is Overall Equipment Effectiveness (OEE) method [6][3].

Pulp and Paper Industries as one of the manufacturing companies in Indonesia that produces dissolving pulp products (fibre rayon) and has reached international market. It is one of the companies that is very important and continue to grow. Based on the information obtained from the fibre line department, the production process of rayon fibre (dissolving pulp) often experience constraints due to the high downtime and losses in the pulp machine resulting in low productivity of the company. This is due to the lack of intensive handling so that the engine suffers damage and disrupts the production process and the quality of products. To overcome this problem, the correct method to use is the OEE method [7]. This method is used to calculate the level of effectiveness and the level of error that occurs in the production process of rayon fibre (dissolving pulp) with OEE method. This method has also been widely applied by Japanese companies as well as some other countries [3][8].

The purpose of this research is to find out the value of *Overall Equipment Effectiveness* (OEE) of *pulp machine* to minimize six *big losses*.

2. Research Methodology

Overall Equipment Effectiveness is a method used as a metric tool in TPM program implementation to keep equipment in ideal condition by avoiding six big losses of equipment. The OEE measurement is based on the measurement of three main ratios, namely (1) Availability ratio, (2) Performance ratio, and (3) Quality ratio. OEE calculations can be done by multiplying these three ratios. Flow diagram of OEE measurement can be seen in **Figure 1** [4] and OEE value measurement formula is as follows:

$$\text{OEE}\,(\%) = Availability \times Performance \times Quality \times 100\% \tag{1}$$

Availability ratio is a ratio that describes the utilization of time available for the operation of machinery or equipment. Nakajima, (1988) states that availability is the ratio of operation time, by eliminating equipment downtime to loading time. Availability can be calculated using formula 2.

$$Availability = \frac{Operating\ time}{loading\ time} \times 100\% \tag{2}$$

Performance ratio is a ratio that describes the ability of the equipment in producing goods. This ratio is the result of operating speed rate and net operating rate. Operating speed rate of equipment refers to the difference between ideal speed (based on equipment design) and actual operating speed. The net operating rate measures the maintenance of a speed during a certain period. The net operating rate measures whether an operation remains stable in the period during which the equipment operates at low speed. The formula performance ratio can be calculated using formula 3.

$$Perf. = \frac{Tot.\ of prod.(processes\ amount)\ x\ ideal\ (theoretical)\ cycle\ time}{operation\ time} \times 100\% \qquad (3)$$

Quality ratio is a ratio that describes the ability of the equipment in producing products that conform to the standard. Quality ratio calculation can be done by using formula 4.

$$Quality = \frac{Net\ produced\ (processes\ amount) - defect\ amount}{Net\ produced\ (processes\ amount)} \times 100\% \qquad (4)$$
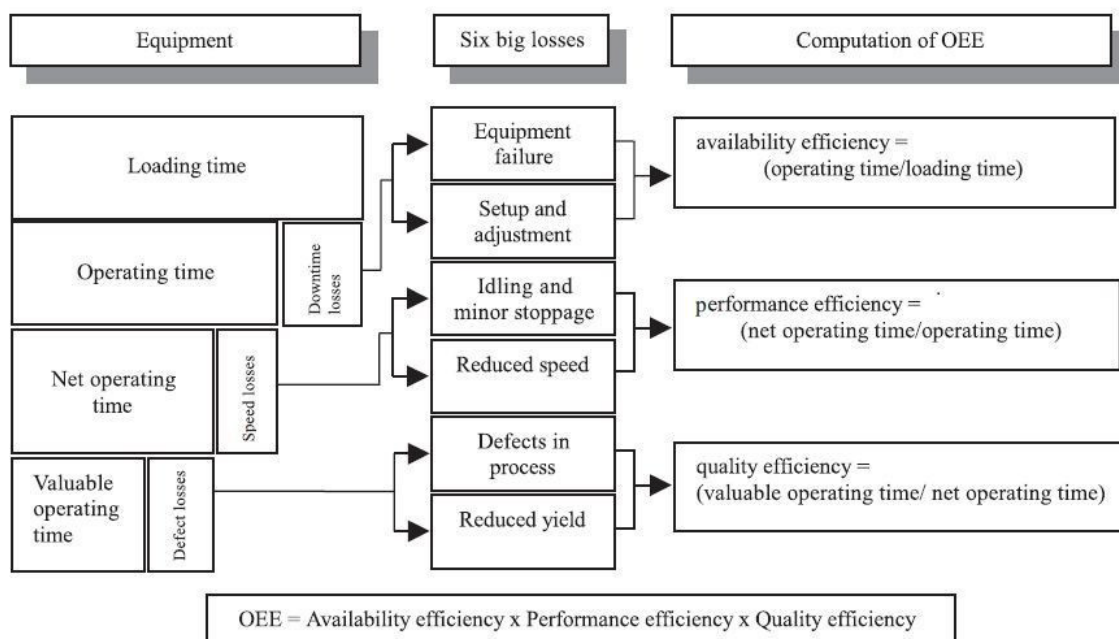

Fig. 1. Overall equipment effectiveness and computation procedure

After the calculation and analysis done, then the next step is drawing the conclusion by following the standards of world-class companies as shown in **Table 1**. Then suggestions are provided for improvement.

Table 1. World Class OEE Factor

OEE Factor	World Class
OEE	>85.0%
Availability	>90.0%
Performance Rate	>95.0%
Quality Rate	>99.9%

3. Results and Discussion

3.1. Availability Rate

Availability is the comparison between the actual operating time and the loading time. Availability rate can be seen in **Table 2**. It can be concluded from the above calculation results that the availability value of pulp machine from January to April 2016 did not experience fluctuating movement. One of the factors that influence the low availability is activity that should be conducted outside the schedule of production activities, so that it can hamper the production process and result in downtime.

3.2. Performance Rate

Performance rate is performance measurement that will describe the speed of the machine in producing in ideal time against the engine operating time. Performance Rate calculation is as shown in **Table 3**.

Table 2. *Availability Rate*

Months	*Loading Time* (minute)	*Planned Downtime* (minute)	*Operating Time* (minute)	*Availability Rate* (%)
Jan.	36270	8370	35410	97.75%
Feb.	33930	7830	33390	98.45%
March	36270	8370	35670	98.39%
April	35100	8100	34320	97.84%
May	36270	8370	31170	86.34%
June	35100	8100	33580	95.47%
July	36270	8370	30390	84.25%
Total	249210	57510	233930	
Average				94.04%

Table 3. *Performance Rate*

Months	Total (Ton)	*Operating Time* (minute)	*Ideal Cycle Time*	*Actual cycle time*	*Performance Rate* (%)
Jan.	16.112	35410	2	2.2	91.0%
Feb.	15.269	33390	2	2.2	91.4%
March	17.674	35670	2	2	99.0%
April	16.410	34320	2	2	95.6%
May	15.235	31170	2	2	97.7%
June	5.870	33580	2	5.9	34.9%
July	11.960	30390	2	2.6	78.7%

Based on the performance rate calculation from January to July 2016 (Table 3), it can be seen that the performance of pulp machine performance in June and July was very low. This is because the operation time that did not reach the ideal cycle time with the number of products produced in each month.

3.3. Quality rate

Quality rate is a measurement of the percentage of the number of products that meet the specification standard of all production. The results of the quality rate calculation can be seen in **Table 4**.

Table 4. *Quality Rate* (Period of January – July 2016)

Months	Defect (Ton)	Net. Product (Ton)	Quality Rate (%)
Jan.	505	15.607	96%
Feb.	1.293	13.976	90.7%
March	1.445	16.228	91%
April	1.301	15.109	91.4%
May	544	14.691	96%
June	-	5.870	100%
July	516	11.443	95%
Average			94.3%

Based on the results of the calculation of the quality rate in Table 3, it can be seen that the value of quality in each month was quite low, although in certain months it increased. The rise in the value of quality in every month was influenced by defective products and good products.

3.4. Calculation of OEE

After obtaining the availability rate, performance rate and quality rate, the next step is to calculate the OEE pulp machine value for the period of January - July 2016. The OEE calculation for January - July 2016 period can be seen in **Table 5**.

Table 5. Overall Equipment Effectiveness value

Months	Availability rate (%)	Performance rate (%)	Quality rate (%)	OEE (%)
Jan.	97.75%	91.0%	96%	85.3%
Feb.	98.45%	91.4%	90.7%	81.6%
March	98.39%	99.0%	91%	88.6%
April	97.84%	95.6%	91.4%	85.5%
May	86.34%	97.7%	96%	80.9%
June	95.47%	34.9%	100%	33.3%
July	84.25%	78.7%	95%	62.9%
Average	94.04%	84.8%	94.3%	74.01%

Based on OEE calculation results in **Table 4**, it can be seen that the average value of effectiveness (OEE) of pulp machine in the period of January - July 2016 was 74.01%. However, based on Table 4, the OEE value had not reached the global standard set by the Japan Institute of Plant Maintenance (JIPM) of > 85%. Among the availability, performance and quality values that make up the OEE value of the pulp machine, the lowest percentage of values is at a performance rate with a percentage rate of only 84.8% (**Table 6**).

In the analysis of six big losses, the highest losses value affecting the low percentage of OEE that is the reduction in speed losses in the amount of 27.6%. The second loss was idle and minor stoppage (15%). The third is equipment failure losses of 6.11% and followed by defect losses of 2.25%, while the value of reduce yield and setup and adjustment losses shared the same value of 0.05%.

Table 6. Comparison between world class measurement and the company measurement.

	OEE company	OEE world class
Availability	94,04%	>90.0%
Performance	84,8%	>95.0%
Quality	94,3%	>99.9%

3.5. Result Analysis

Based on the calculation of the effectiveness value (OEE) of the pulp machine, it was found that the losses that have the most effect on the effectiveness of the machine was reduced speed losses which is 27.6%. This loss occurs because the engine speed decreases, so the engine does not operate optimally. After knowing that the reduce speed losses is the biggest factor causing the decreasing

effectiveness of the machine, next is to identify the cause of the reduction speed losses. Among its factors are human factor (lack of intensive maintenance, lack of supervision on engine roll speed and mismatch setting), engine factor (wear on press roll, dewatering, wear on bottom and top ware), and raw material (high water content of pulp). Based on these factors, actions needed to be taken to avoid the occurrence of reduce speed losses are as follows:

1) Maintain the actual speed of operation as the standard engine speed which is 118 rpm.
2) Maintain wear on each roll with a maximum wear value of <40%.
3) Keep the speed of rotation on the role of the pulp machine with the standard of 118 rpm.
4) Maintain the suitability of machine settings.
5) Conduct intensive monitoring and maintenance.
6) Keep the water content of the pulp in accordance with the predetermined standard (10%).

4. Conclusion

The conclusion that can be drawn from the discussion of OEE measurement is that the average level of machine effectiveness in pulp machine for period January - July 2016 was 74.01% and according to Japan Institute of Plant Maintenance (JIPM), the value has not reached the standard, which is> 85%, however, the improvement is possible to happen. The losses that have the most significant effect on the low effectiveness of the overall equipment of the pulp machine is reduced speed in the amount of 27.6%. To minimize the losses, one of the ways that can be done is by maintaining the actual speed of operation and maintains the wear on each roll of pulp machine.

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