A framework to improve equipment effectiveness of manufacturing process - a case study of pressing station of crude palm oil production, Indonesia

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Abstract. Overall Equipment Effectiveness (OEE) has been widely used to measure the performance of the production process. A well-performing company is a company that has a high OEE score. Increased the OEE score can be done by minimizing six big losses that greatly affect the score of OEE. In this paper, a framework to determine the actions needed to minimize the six big losses is recommended. The framework was then used to determine the action to minimize the six big losses in palm oil mills. A total of 7 actions were required. The highest ranked action, the most important action, was the improvement of raw material quality while the lowest ranked action was to increase the number of workers.

1. Introduction

The lean manufacturing system is an effective method to improve operational efficiency, which as a systematic approach for eliminating waste (non-value added) in all its forms while enabling continuous improvement. The benefits of lean manufacturing include the potential to improve productivity, customer satisfaction, profit, customer responsiveness, capacity, quality, cash flow, on-time delivery, and worker morale while decreasing costs, defects, lead times, inventory effort, space and overall waste.

There are some tools for lean manufacturing. Among of them are takt-time, error proofing (poka-yoke), single piece flow, work standardization, visual management, waste identification & Elimination, workplace organization (5S), material 'pull' system, Overall Equipment Effectiveness (OEE), Total Productivity Maintenance (TPM), Kaizen, Value Stream Mapping (VSM), automation, policy deployment, change over reduction (SMED), process mapping, cellular manufacturing, Quality Function Deployment (QFD), multipurpose handling and six sigma [1]. Based on [2], there are 66 lean practice factor implementations to assess lean company performance. Among lean tools and techniques, the Total Productive Maintenance (TPM) is one of favor adopted by manufacturing company. The TPM means good maintenance that will improve productivity [3]. Reducing waste to increase productivity can lead to enhance the financial performance of a manufacturing company.

The TPM is purposed to optimizes equipment effectiveness and maintain optimal equipment conditions to improve productivity through eliminating big losses such as equipment failure, setup, and
adjustment loss, idling and minor stoppage, reduced speed, defects in the process and reduced yield [4]. The TPM uses Overall Equipment Effectiveness (OEE) as a quantitative metric to measure the performance of a productive system. The measuring of the performance of production systems is based on its availability, performance efficiency and quality rate of output [5]. The availability, performance efficiency and quality rate of output are influenced by six type of losses, which known as Six Big Losses as shown in Table 1.

Improving OEE is means reducing the six big losses. To reduce these losses is effective, the action that will be done by identifying one carefully. The action needs to be ranked based on its level of importance.

| Performance aspects       | Relating losses                      |
|---------------------------|--------------------------------------|
| 1 Availability rate       | Equipment failure/breakdown losses   |
|                           | Set-up and Adjustment losses          |
| 2 Performance efficiency  | Idling and minor stoppages           |
|                           | Reduced speed                         |
| 3 Quality rate            | Defect and rework losses              |
|                           | Start-up losses                       |

In this paper, a framework for reducing the six big losses to improve OEE is purposed. The proposed framework was used to reducing six big losses in the manufacturing process of crude palm oil in Indonesia.

2. Lean Manufacturing, TPM and OEE

2.1. Lean Manufacturing

An assessment framework to measure improvement by the respective company to adopt lean manufacturing can be divided into five perspectives [6] and 66 lean performance indicators [1]. The five perspectives are [6]: (a) financial: focused on profitable and productivity, (b) customers/market measures, which was considered by customers and supplier issues, (c) process: the indicators were selected by manufacturing and internal management, manufacturing efficiency, research, and development, (d) people: internal management, manufacturing efficiency and learning perspective and (e) future: research and development, and investment priority. The lean manufacturing implementation framework can be seen in Figure 1.

Figure 1. The framework of performance indicators to measure lean manufacturing implementation
Implementation of lean manufacturing is influenced by to extend the organization or company adopted the lean performance indicator such as the TPM. The TPM approach can be considerate for introducing maintenance success in the organization or company activities [Ahmed et al., 2004; Graisa and Al-Habaibeh, 2010]. Implementing the TPM approach to maintain manufacturing equipment or machine can be eliminated such as various losses of the defect, downtime and speed losses at its losses sources [Ahmed et al., 2004; Ahuja and Khamba, 2008].

2.2. Total Productive Maintenance (TPM)
TPM is part of lean manufacturing, which is one of the maintenance processes developed to improve productivity and effectiveness in the work area so that the process can be run optimally without any waste. The TPM is an innovative maintenance method to optimizing equipment effectiveness, eliminating losses such as unexpected breakdowns, speed losses and quality defects occurring from process activities and promoting autonomous maintenance by operators through daily activities involving the entire workforce [4]. According to [7], TPM is a life-cycle approach integrated with factory maintenance, which endeavours to maximize equipment effectiveness. The TPM can be effectively utilized by the organization to develop workers' involvement in every step of the manufacturing and maintenance process to streamline production flow further, improve product quality and reduce operating costs. Total employee involvement, autonomous maintenance by the operator, group discussion to improve reliability, maintainability, equipment productivity and continuous improvement are the principles covered by the TPM [4,7]. The TPM provides a way to gain perfection in planning, organizing, monitoring and controlling through its unique eight pillar methods that consisting of autonomous maintenance; focused maintenance; planned maintenance; quality maintenance; education and training; TPM office; development management; safety, health and environment [8].

The TPM implementation strategic can also facilitate achieving the various organizational manufacturing priorities and goals, in term of the equipment/machine’s availability, performance, and quality. The TPM goal for the availability of the equipment/machine is no stops such as breakdowns and planned stops such as changeovers to eliminate productivity losses. The TPM goal to prevent productivity losses in term of performance of the equipment/machine is no small stops or slow running (cycles). The TPM goal for the quality of the equipment/machine is no defects such as production rejects and the reduced yield on start-up. Therefore, the TPM goal making production processes optimally is strongly influenced by the OEE components (availability, Performance efficiency, and quality). According to Gregory (2006), the OEE enhancement can be steered a lean manufacturing system.

2.3. OEE (Overall Equipment Effectiveness)
The OEE metric is a core of the TPM improvement strategy by continuously and systematically addressing the big losses sources and wastes inherent in the manufacturing processes systems [9]. The OEE world class standards factors are 90 percent availability rate, 95 percent of performance efficiency rate and a 99 percent rate of quality, and the OEE measure of 85 percent [10]. The OEE is calculated from equipment availability, performance efficiency, and machine/equipment capability to produce quality products that are formulated as below [4]:

\[
\text{Availability} = \frac{\text{Loading Time} - \text{Downtime}}{\text{Loading Time}} \times 100\% \quad (1)
\]

\[
\text{Performance Eff.} = \frac{\text{Output} \times \text{Ideal Cycle Time}}{\text{Operating Time}} \times 100\% \quad (2)
\]


\[
Quality\ Ratio = \frac{Output - Reduced\ Yield - Reject}{Output} \times 100\% \tag{3}
\]

\[
OEE = Availability \times Performance \times Quality\ Ratio \tag{4}
\]

The main objective of the TPM is to eliminate or minimize all losses associated with the manufacturing system. So that it will improve overall production efficiency. The TPM based OEE metrics focus on addressing big losses such as equipment failure, setup, and adjustment loss, idling and minor stoppage, reduced speed, defects in the process and reduced yields (Figure 2), which considered significant in lowering the efficiency of productivity [8].

![Figure 2. The big losses [8]](image)

However, it needs a decision-making approach to identify the action needed to minimize big losses related to equipment availability, performance efficiency, and product quality. Furthermore, a method for determining the priority of the action can be adopted from Tasri & Susilawati [11]. They developed a multi-criteria decision-making method based on Fuzzy AHP (Analytical Hierarchy Process). They constructed a new procedure for the aggregation of expert opinions using selection criteria and sub-criteria. Because each criterion has their relative importance, hence it should be weighted to indicate their degree of importance. The weight criteria are formed by a pair-wise comparison using Fuzzy AHP.

3. Methodology
Increasing OEE is a means of minimizing the causes of the six big losses in manufacturing. The cause can be identified by using a fishbone diagram. The action that needs to be done is then determined from the list of causes of the loss. In some companies, reducing all losses at one time is not easy because of the limited amount of resources such as finance and the number of workers. Companies must set priorities, ranging from the most important to the less important. Once the ranking has been made the next step is to determine how far the action to reduce the loss should be done. For this purpose a framework is proposed as following:

1. Measure the current score of OEE.
2. Compare the OEE with its benchmark value. The low OEE of the benchmark shows there are losses occurring
3. By using six big losses as a reference, find the cause of the losses
4. Determine action to reduce the losses.
5. Rank the action based on their importance level.
3.1. Measuring score of OEE
The scores of OEE in term of equipment availability, performance efficiency and quality product are computed by using equations (1-4).

3.2. Finding the cause of losses
All causes of losses can be found by finding the cause of each component of the six big losses by using a fishbone diagram.

3.3. Determine action to minimize the losses
After the cause of losses is found, the next step is to determine what action needs to be done to minimize the losses. These assigned actions are often not performed perfectly due to limited funds and resources, so it is necessary to establish the extent to which an action will be taken. For this purpose, it is necessary to define a variable associated with the losses and measure the present value of the variable and determine the target value to be achieved. The target value can be determined based on past operating experience or the value of that variable on another company that is considered better.

As an illustration, in reducing the first component of the six losses of "equipment failure," the action chosen is "increase the number of workers." To decide how much the number of workers needs to be added, a measured variable relating to the "equipment failure" is defined. The variable is "number of hours of operation." The next step is to calculate the "number of hours of operation" at this time, and the set target value will be achieved.

3.4. Rank the Action Base on Their Importance Level
The effect of each component of the six big losses differs on each firm. In a particular company, each component of the six big losses may have the same effect; another company may be a certain dominant more dominant than others. So the company needs to rank the component based on its level of influence on the company's operations. Ranking can be done by giving a weight for each component. The components are considered important that are given a higher weight.

Due to corporate limitations, not all specified actions can be fully implemented. The preferred action is the most important action. So for each component of the losses, the action needs to be ranked by weighting each action. Furthermore, the rank of the action is determined as the multiplication of the weights of the action with the weight of the losses component associated with the action.

As an illustration, the components of the six big losses are, A, B, C, D, E and F. Each weights WA...WA6. The action to be taken to reduce A is a1, a2, a3 with weight wa1…wa3. The same is true for B, C, D, E, and F as shown in Table 2.

The final weight of action a1 is (WA x Wa1). The same is true for other actions. The complete final weight is shown in Table 3. In Table 3, the final weight of a2 is calculated as (WA x Wa1 + WB x Wb2) because action a1 is needed to overcome losses A and B.

Weight can be determined by using fuzzy AHP as suggested by Tasri and Susilawati [11]. The weight of the number of elements is determined by comparing the elements in pairs. A comparison score is given based on the importance of an element against its comparative element. The score is in the range of 1...9. Score 1 means the two comparable components have the same level of importance, while score 9 means the first element is very important than the second element. Scores are awarded by one or more experts. Scores of each expert are then combined and used to determine the value of weight.

| Six Big Losses | Action | Components | Weight | Components | Weight |
|----------------|--------|------------|--------|------------|--------|
| A              | WA     | a1         | Wa1    |            |        |
### Table 3. Final weight

| Action | Weight |
|--------|--------|
| a1     | WA x Wa1 + WB x Wb2 |
| a2     | WA x Wa2 |
| a3     | WA x Wa3 |
| b1     | WB x Wb1 |
| b2     | WB x Wb3 |
| c1     | WC x Wc1 |
| c2     | WC x Wc2 |
| c3     | WC x Wc3 |
| c4     | WC x Wc4 |
| d1     | WD x Wd1 |
| d2     | WD x Wd2 |
| d3     | WD x Wd3 + WF x Wf2 |
| e1     | WE x We1 |
| e2     | WE x We2 |
| e3     | WE x We3 |
| f1     | WF x Wf1 |

3.5. **OEE Calculation in pressing station of crude palm oil production**

This research was conducted a case study in the PTPN V Sei Pagar, Indonesia. The company is engaged in the palm oil processing industry that produces Crude Palm Oil (CPO) and kernels. A data was collected on the pressing line that has four machine screw presses. The screw press is a tool in the forging unit of a palm oil mill that serves to remove oil from the flesh by pressing. The process was squeezing row fruit palm, and that has been chopped and crushed inside the digester to get crude oil. Fruits that have been stirred gradually with the help of throwing knives inserted into the screw conveyor feed and push it into the twin screw press. By the pressure of the screw held by the cone, the mass is
squeezed so that through the press holes, the oil is separated from the fibers and the seeds. Further, resulting crude oil is going to the clarification station, while the dregs and seeds enter the kernel station.

In this paper was limited just 1 of 4 machines would be discussed and analyzed (an example). The length of collection data was two months, 01/09/2016 to 31/10/2016. Data was collected in this research: working time of the machine (in shift work); planned downtime, the time was allocated to implement preventive maintenance or other maintenance activities that have been scheduled in advance; failure and repair, time without producing output due to engine failure and the time it takes to fix it; setup and adjustment time, the time was required at the start of production for example in the form of machine heating and spare part adjustment; reduced yield, the amount of product damage that occurs during setup and adjustment; reject and rework, the number of rejects/defective production results when the process continues; output, the amount of production on the machine. Then, the OEE values were calculated in term of the availability, performance and quality used formula (1-4).

The data was collected in the case study company that can be seen in Table 4. The calculation of OEE values, availability ratio, performance ratio, and quality ratio are depicted in Table 5. The case study result revealed the average value of OEE was 62.2%. This condition indicated the ability of screw press machine had not reached the standard World Class (85%).

Then, the value rate of six big losses was set up and adjustment losses of 32.63%, equipment failure losses of 3.31%, reduced speed losses 1.87%, idling and minor losses 1.87%, reduced yield/scrap losses of 0%, and defect and rework losses of 0%. Based big losses analysis in Table 6, the factor of set up and adjustment losses was the biggest contribution in decreasing OEE value with the average percentage of 32.63%.

3.6. Identify the problem that causes the lower value of the OEE in the case study company

The identifying of the problem causing each component of six big losses in the case study company is depicted in Table 7.

### Table 4. Collection data research

| Date       | Working time (Minute) | Planned Down time (Minute) | Failure & Repair (Minute) | Set Up & Adj (Minute) | Reduced Yield (Ton) | Reject & Rework (Ton) | Output (Ton) | Shut down (Minute) |
|------------|-----------------------|-----------------------------|---------------------------|-----------------------|---------------------|-----------------------|--------------|-------------------|
| 01-07 Sept.| 10080                 | 1440                        | 330                       | 0                     | 0                   | 0                     | 1328.82      | 495               |
| 08-15 Sept.| 11520                 | 0                           | 440                       | 0                     | 0                   | 0                     | 1568.49      | 1500              |
| 15-22 Sept.| 10080                 | 0                           | 555                       | 0                     | 0                   | 0                     | 1591.03      | 60                |
| 23-30 Sept.| 11520                 | 720                         | 300                       | 0                     | 0                   | 0                     | 592.82       | 6930              |
| 01-08 Oct. | 11520                 | 0                           | 0                         | 0                     | 0                   | 0                     | 1115.8       | 4320              |
| 09-16 Oct. | 11520                 | 0                           | 600                       | 0                     | 0                   | 0                     | 1448.6       | 2340              |
| 17-24 Oct. | 11520                 | 0                           | 0                         | 0                     | 0                   | 0                     | 87.6         | 10980             |
| 25-31 Oct. | 10080                 | 0                           | 540                       | 0                     | 0                   | 0                     | 1115.8       | 2460              |

### Table 5. The calculation of OEE

| Date       | Availability ratio | Performance ratio | Quality ratio | OEE  |
|------------|--------------------|-------------------|---------------|------|
| 01-07 Sept.| 90.45%             | 85.71%            | 100.00%       | 77.53%|
| 08-15 Sept.| 83.16%             | 100.00%           | 100.00%       | 83.16%|
| 15-22 Sept.| 93.90%             | 100.00%           | 100.00%       | 93.90%|
| 23-30 Sept.| 33.06%             | 93.75%            | 100.00%       | 30.99%|
| 01-08 Oct.| 62.50%             | 100.00%           | 100.00%       | 62.50%|
9-16 Oct 74.48% 100.00% 100.00% 74.48%
17-24 Oct 4.69% 100.00% 100.00% 4.69%
25-31 Oct 70.24% 100.00% 100.00% 70.24%
Average 64.06% 97.43% 100.00% 62.2%

Table 6. The big losses percentages

| The big losses                  | Total time losses (minute) | Percentage cumulative (%) | Percentage (%) |
|--------------------------------|---------------------------|---------------------------|----------------|
| Setup and adjustment losses    | 290.89                    | 84.24                     | 32.63          |
| Equipment fault losses         | 27.65                     | 92.24                     | 3.31           |
| Reduced speed losses           | 13.396                    | 96.12                     | 1.87           |
| Idle minor losses              | 13.396                    | 100.00                    | 1.87           |
| Reduced yield/scrap losses     | 0                         | 100.00                    | 0.00           |
| Defect and rework losses       | 0                         | 100.00                    | 0.00           |

3.7. Define action to minimize the problem in case study company

The action to eliminate the six big losses problem can be seen in Table 7.

Table 7. The identifying losses causes and action in the case study company

| Main Factor  | Six Losses | Cause                        | Action                           |
|--------------|------------|------------------------------|----------------------------------|
| Availability | Equipment failure | Overload | Avoid overloading             |                                 |
|              |            | Wear and damage of machine components | Replace wear and damage of machine components |
|              |            | Low quality of raw material | Improve quality of raw material |
| Setup and adjustment losses | Insufficient number of worker | Increase number of worker | Re-training the worker |
| Setup and adjustment losses | Un-skilled worker | Increase number of worker | Re-training the worker |
| Setup and adjustment losses | Un-clean and un- tidy work environment | Improve quality work environment | |
| Performance | Idle minor stop losses | Low worker motivation | Improve worker motivation | |
| Performance | Idle minor stop losses | Insufficient number of worker | Increase number of worker | |
| Performance | Idle minor stop losses | Wear and damage of machine components | Replace wear and damage of machine components | |
| Performance | Idle minor stop losses | Low quality of raw material | Improve quality of raw material | |
| Performance | Idle minor stop losses | Un-skilled worker | Re-training the worker | |
| Reducing speed loss | Insufficient number of worker | Increase number of worker | Re-training the worker |
| Reducing speed loss | Wear and damage of machine components | Replace wear and damage of machine components | |
| Reducing speed loss | Low quality of raw material | Improve quality of raw material | |
| Reducing speed loss | Un-clean and un-tidy work environment | Improve quality work environment | |
| Quality rate | Defect | Un-skilled labour | Re-training the worker | |
| Quality rate | Defect | Low quality of raw material | Improve quality of raw material | |
| Quality rate | Defect | Wear and damage of machine components | Replace wear and damage of machine components | |
| Quality rate | Defect | Un-clean and un-tidy work environment | Improve quality work environment | |
| Reduced yield loss | Insufficient number of worker | Increase number of worker | Re-training the worker | |
| Reduced yield loss | Wear and damage of machine components | Replace wear and damage of machine components | |
| Reduced yield loss | Low quality of raw material | Improve quality of raw material | |
| Reduced yield loss | Un-clean and un-tidy work environment | Improve quality work environment | |

3.8. Rank the action base on its urgency

The scores of pair-wise comparison of the six big losses were collected from experts to determine the weights. Then, the similar manner was done for action to be taken to eliminate the losses causes. Resulted in weights by the expert’s opinion on the six big losses and the action to solve the problems can be seen in Table 8.
The final weights were a summation of final weight from each loss that shown in Figure 3. Interestingly, the action to improve raw material quality awarded the highest weight score of 0.35. It was followed by replacing wear and damage of machine components of 0.24. While, the actual result from the case study company, was found the factor of set up and adjustment losses that was the biggest contribution in decreasing OEE value with the average percentage of 32.63%. However, based expert opinion one was awarded 0.1 of weight score and equipment failure got highest weight score of 0.51 (Table 8). The action ranking to eliminate set up and adjustment losses are depicted in Figure 4.

Table 8. The weights scores by the experts’ opinion for six big losses and action to eliminate caused losses

| Main Factor   | Six Losses            | Weight | Cause                          | Action                          | Action                          | Weight |
|---------------|-----------------------|--------|--------------------------------|---------------------------------|---------------------------------|--------|
| Setup and adjustment losses | Equipment failure | 0.51   | Overload                       | Avoid overloading               | Improve quality of raw material | 0.23   |
|               |                       |        | Wear and damage of machine components | Replace wear and damage of machine components | Improve quality of raw material | 0.14   |
|               |                       |        | Low quality of raw material | Improve quality of raw material | Increase number of worker     | 0.07   |
|               |                       | 0.10   | Insufficient number of worker | Increase number of worker       | Re-training the worker         | 0.04   |
|               |                       |        | Un-skilled worker              | Re-training the worker          | Improve quality work environment | 0.49   |
| Performance efficiency | Idling and minor stop losses | 0.05   | Low worker motivation          | Improve worker motivation       | Improve quality of raw material | 0.33   |
|               |                       |        | Wear and damage of machine components | Replace wear and damage of machine components | Improve quality of raw material | 0.40   |
|               |                       |        | Low quality of raw material | Improve quality of raw material | Increase number of worker     | 0.05   |
|               |                       |        | Un-skilled worker              | Re-training the worker          | Improve quality work environment | 0.16   |
|               |                       |        | Wear and damage of machine components | Replace wear and damage of machine components | Improve quality work environment | 0.07   |
|               |                       | 0.08   | Un-skilled worker              | Re-training the worker          | Improve quality of raw material | 0.11   |
|               |                       |        | Insufficient number of worker | Increase number of worker       | Improve quality of raw material | 0.04   |
|               |                       |        | Wear and damage of machine components | Replace wear and damage of machine components | Improve quality work environment | 0.40   |
|               |                       |        | Low quality of raw material | Improve quality of raw material | Increase number of worker     | 0.05   |
|               | Reduce speed losses   | 0.22   | Un-skilled labour              | Re-training the worker          | Improve quality work environment | 0.13   |
|               | Quality rate          |        | Low quality of raw material | Improve quality of raw material | Increase number of worker     | 0.33   |
|               | Defect                |        | Wear and damage of machine components | Replace wear and damage of machine components | Improve quality work environment | 0.35   |
|               | Reduced yield         | 0.04   | Un-skilled labour              | Re-training the worker          | Improve quality work environment | 0.53   |

Figure 3. The final weight action score for eliminating problems in six big losses
Figure 4. The weight scores to action in the elimination of set up and adjustment losses.

4. Conclusion
A framework for improving OEE is proposed in this paper. Those steps are: (a) measure current score of OEE, (b) identify problems that causing the lower value of OEE, (c) define the action to eliminate causing of the losses and (d) rank the action based on its urgency.

The proposed framework was applied as a case study on the pressing station of the crude palm oil manufacturing company. The case study result revealed the effectiveness value rate of 62.2% that was below the word class standard of 80%. Then, the value rate of six big losses was set up and adjustment losses of 32.63%, equipment failure losses of 3.31%, reduced speed losses 1.87%, idling and minor losses 1.87%, reduced yield/scrap losses of 0%, and defect and rework losses of 0%.

Regarding eliminate the source of the problem caused losses, there were needed seven actions. The action from the most important to the less important are:
1. Improve the quality of raw material
2. Replace wear and damage of machine components
3. Avoid overloading
4. Re-training the worker
5. Improve quality work environment
6. Improve worker motivation
7. Increase number of worker

It would be recommended in the case study company to reduce the higher occurring losses that can be the adoption of TPM pillars such as autonomous, focused and planned maintenances; quality maintenance; education and training; safety, health, and environment; and continues improvement.

Further research is needed to find a target of improvement approaches, such as using previous data and the multi-perspectives, which consist of dynamic performance actions that can help a company to measure its OEE progress toward and enable decisions to be made on its strategies and activities for continuous improvement.

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