Wastes Analysis to Improve the Productivity and Sustainability in Manufacturing Industry

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Abstract. The eliminate wastes in manufacturing processes can be reinforcement for achieving sustainable manufacturing industry. This paper proposed to develop a framework to analyze an Overall Equipment Effectiveness (OEE) implementation to eliminate wastes for productivity improvement, and it’s correlated to sustainability in manufacturing Industry. An analyze wastages in term OEE is used the six big losses i.e. equipment failure, setup and adjustment loss, idling and minor stoppage, reduced speed, defects in process and reduced yields. The framework employed the Fuzzy AHP (Analytic Hierarchy Process) based OEE measurement. The case study from a crude palm oil manufacturing company was presented to strengthen the proposed method. Therefore, the framework can assist the top management in the company to decide the priorities to increases productivity and it’s correlated to manufacturing sustainability.

1. Introduction
The sustainable manufacturing processes is described minimizes waste in the environmental impact, which used processes by eliminate losses, conserve energy and natural resources; secure employees, communities and consumers; and healthy economy [1], [2]. According to [3]-[8], sustainable manufacturing has synergy and correlation to lean manufacturing system. The synergy and correlation between lean and sustainable (green) manufacturing can be improved environment aspects in term of resource consumption, recycling, remanufacturing, returnable packaging and waste management [4]-[8]. Environmental benefits of lean tools and techniques has discussed by EPA [9], which is developed lean wastes and the environmental impacts.

According to EPA [9], potential environmental advantages of lean such as “fewer defects-reduces energy and resource needs; avoids waste increased longevity of equipment decreases need for replacement equipment and associated environmental impacts (energy, raw materials, etc)” [9]. Therefore, impact of integrated lean practice factor implementations on the environment would be reduced waste to increased productivity that lead to enhance the financial performance of manufacturing company. Among of various lean tools and techniques [10], in this paper focused to OEE (Overall Equipment Effectiveness).

The OEE is purposed to optimizes equipment effectiveness and maintain optimal equipment conditions to improve productivity through eliminate big losses such as equipment failure, setup and adjustment loss, idling and minor stoppage, reduced speed, defects in process and reduced yield [11], [12]. The main objective of the OEE is to eliminate or minimize all losses associated with the manufacturing system to improve overall production effectiveness.
The OEE metric is an improvement strategy by continuously and systematically addressing the big losses sources and wastes inherent in the manufacturing processes systems [13]. The OEE metric implementation in term of equipment availability, performance efficiency of process and quality performance of manufacturing processes based analyses big losses that could be a deserving future the manufacturing sustainability [14]. Therefore, it has been challenged for manufacturing industries to adoption of sustainable manufacturing approach incorporate with eliminate wastages/losses to increasing their productivity in competitive market recently.

A number of researchers have created framework and assessment tools, which allow the company/organization to measure their lean manufacturing practice tools and techniques and its link to sustainable manufacturing [1], [3], [8], [9], [12], [14]. A case study implementation example was done by Miller et al [8] who used Kaizen event to development of liquid/solid waste disposal and recycling program. Mahmood et al [14] developed a framework of incorporate between OEE metric and sustainable manufacturing. They constructed system availability, object performance, and product quality from OEE factors were indirectly has a good impact on environmental conservation, social efficiency, and economic power of manufacturing companies. However, they stated the framework has excluding big losses analysis [14]. More, Domingo and Aquido [15] developed a new OEE metric for post implementation of lean and green manufacturing to advance analyses between OEE and sustainable manufacturing. They created a formula Overall Environmental Equipment Effectiveness (OEEE) that was to identify the losses due to sustainability to improve productivity as OEE multiplied by sustainability [15]. However, it needs a decision making method to priorities and ranking the big losses related to sustainability.

In this paper, a framework is developed to assesses and analyses the effectiveness equipments using OEE metric to eliminate big losses in the manufacturing system and its association to sustainable manufacturing. The Fuzzy AHP (Analytic Hierarchy Process) method is adopted for developing a framework as an assessment tool, which allow the company/organization to measure and analyzing losses/wastes to improve their productivity, which synergy and correlation to sustainability in Manufacturing Industry. A case study was done in the pressing line on manufacturing processes of a crude palm oil company to validate the proposed method.

2. Methodology

A multi criteria decision making method based Fuzzy Analytic Hierarchy Process (FAHP) was employed to develop assessment tool for losses analysis of productivity improvement and it’s correlated to sustainability in manufacturing Industry. The methodology to analyses the big losses and sustainability to improve productivity was adopted from Tasri & Susilawati [16]. The proposed framework to assess and analyses the effectiveness equipments using OEE metric based FAHP was composed of the following steps:

Step 1: Collect the information of OEE achievement to compute six big losses: setup and adjustment losses, equipment fault/breakdown losses, reduced speed losses, idle minor losses, reduced yield/scrap losses, defect and rework losses.

The formula to calculate the six big losses as following [11]:

$$\text{Breakdown losses} = \left( \frac{\text{Total breakdown time}}{\text{Loading time}} \right) \times 100\% \quad (1)$$

$$\text{Set up/adjustment losses} = \left( \frac{\text{Total setup and adjustment time}}{\text{Loading time}} \right) \times 100\% \quad (2)$$

$$\text{Idling and minor stoppages losses} = \left( \frac{\text{non production time}}{\text{loading time}} \right) \times 100\% \quad (3)$$

$$\text{Reduce speed losses} = \left( \frac{\text{ideal cycle time} \times \text{total actual produk}}{\text{loading time}} \right) \times 100\% \quad (4)$$
Rework losses = \frac{\text{ideal cycle time \times rework}}{\text{loading time}} \times 100\% \tag{5}

Reduced yield losses = \frac{\text{ideal cycle time \times scrap}}{\text{loading time}} \times 100\% \tag{6}

Step 2: Identify the criteria and sub-criteria to be used in the framework model based OEE achievement in step 1 and it’s correlated to sustainable manufacturing. The criteria was adopted from [1], [3], [8], [9], [12], [14], [16], C1: Quality of the energy source, C2: Socio-political, C3: Economic, C4: Technological and C5: Environmental. Whilst, the sub-criteria for this proposed method was employed the OEE metric consist of equipment availability, performance efficiency and machine/equipment capability to produce quality products [11], [12], [14], [17] and the losses due to sustainability to improve productivity [15].

The OEE world class standards factors are 90 percent availability rate, 95 percent of performance efficiency rate and 99 percent rate of quality, and the OEE measure of 85 percent [17]. The OEE is calculated from equipment availability, performance efficiency and machine/equipment capability to produce quality products that is formulated as below [11]:

\begin{align*}
\text{Availability} &= \frac{\text{Loading Time - Downtime}}{\text{Loading Time}} \times 100\% \tag{7} \\
\text{Performance Eff.} &= \frac{\text{Output \times Ideal Cycle Time}}{\text{Operating Time}} \times 100\% \tag{8} \\
\text{Quality Ratio} &= \frac{\text{Output - Reduced Yield - Reject}}{\text{Output}} \times 100\% \tag{9} \\
\text{OEE} &= \text{Availability} \times \text{Performance Eff.} \times \text{Quality Ratio} \tag{10}
\end{align*}

Step 3: Construct a hierarchically model based on the criteria and sub-criteria/alternatives identified at Step (2).

Step 4: Determine the degree of importance, also known as weights of the criteria and sub-criteria/alternatives by using FAHP method. The steps for FAHP used in this proposed method are as follows [16]:

- Establish a decision group,
- Members of the decision groups make a judgment on importance of the OEE implementation to eliminate wastes for productivity improvement, and it’s correlated to sustainability in manufacturing Industry,
- Aggregate judgments of the decision maker,
- Check consistence,
- Calculate the weight.

The weight criteria were formed by a pair-wise comparison using Fuzzy AHP. Then, the sub-criteria in each main weight are also formed using Fuzzy AHP procedure.

Step 5: Calculate and scoring of losses analysis to improve the productivity and sustainability in step (4), and then it is ranked to decide the priority.

3. Result and Discussion

The first step to develop assessment tool for losses analysis of productivity improvement and it’s correlated to sustainability in manufacturing industry was collect the information of OEE achievement to compute six big losses. In this paper, the OEE data was collected in the PTPN V Sei Pagar, Indonesia [18]. Based OEE achievement was computed the six big losses: setup and adjustment losses, equipment fault/breakdown losses, reduced speed losses, idle minor losses, reduced yield/scrap losses, defect and rework losses. A data was collected on 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. 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. The data collections in the case study company can be seen in Table 1.

The OEE values were calculated in term of availability, performance and quality using formula (7-10). The calculation of OEE values was depicted in Table 2. During September 2016 - October 2016 was obtained availability values of screw press machine about 4.69% - 93.9% with the average availability value of 64.06%. The value of performance efficiency was 85.71% - 100%, an average performance efficiency of 96.99%. The average value of the quality products was a 100%. Hence, the result of the OEE ranging was 4.69% to 93.90%, which the average value of OEE of 62.2%. This condition indicated the ability of screw press machine had not reached the standard World Class (85%).

The big losses were computed by using the formula 1-7 and the result that can be seen in Table 3. The factor of set up/adjustment losses was the biggest contribution in decreasing OEE value with the average percentage of 32.63%. Whilst, the absorbed time for losses in the set up & adjustment losses factor was 290.89 minutes.

Table 1. Collection of the OEE data [18].

| Date          | Working time (Minute) | Planed Downtime (Minute) | Failure & Repair (Minute) | Set Up & Adj. (Minute) | Reduced Yield (Ton) | Reject & Rework (Ton) | Output (Ton) | Shutdown (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                        | 600                       | 0                      | 0                   | 0                     | 1138.48      | 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 2. The calculation of OEE [18].

| Date          | Availability ratio | Performance ratio | Quality ratio | OEE |
|---------------|--------------------|-------------------|---------------|-----|
| 01-7 Sept     | 90.45%             | 85.71%            | 100.00%       | 77.53% |
| 8-15 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% |
| 09-16 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 3. The percentages of six big losses [18].

| 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

Next step, the proposed framework was constructed the structure of interrelation of decision that was explained in five criterion, four sub-criterion and six big losses alternatives. To analyzed the losses contribution on productivity and sustainability was adopted Fuzzy AHP method in paper [16]. In the first level was a goal to improve the productivity and sustainability in pressing line of crude palm oil production. The goal is break into the five of main criterion, which adoption synthesis from paper [1], [3], [8], [9], [12], [14], [16] i.e. environmental, energy conservation, technological, economic and socio-political. And, each main criterion has sub-criteria: system availability, performance efficiency, production quality and sustainability [11], [12], [14], [15], [17]. Alternative to eliminate big losses was setup and adjustment, equipment fault, reducing speed, idle minor, reduced yield/scrap, defect and rework that was 32.63%, 3.31%, 1.87%, 1.87%, 0.00% and 0.00% respectively.

Furthermore, it was establishing into hierarchical structure of interrelated decision, which consists of the goal, criteria, sub-criteria and alternative that can be seen in Figure 1. The scores of pair-wise comparison of the main criteria were collected from expert to determine the weight on main criterion factors. Then, the similar manner was done for sub-criteria. Resulted weights of the main criteria and sub-criteria by the expert opinion can be seen in Table 4.

![Figure 1. A losses analysis hierarchy to improve the productivity and sustainable manufacturing.](image)

Table 4. The weights of main criteria and sub-criteria by the expert opinion and scores result for six big losses.

| Main criteria     | Sub-criteria          | Weights | Setup & adjustment losses (32.63%) | Equipment fault losses (3.31%) | Reduced speed losses (1.87%) | Idle minor losses (1.87%) | Reduced yield losses (0%) | Defect & rework losses (0%) |
|-------------------|-----------------------|---------|------------------------------------|-------------------------------|-----------------------------|--------------------------|--------------------------|----------------------------|
| Environmental     | -Sustainability       | 0.192   | 6.428                              | 0.652                         | 0.368                       | 0.368                    | 0                        | 0                          |
|                   | -Performance efficiency| 0.219   | 1.980                              | 0.201                         | 0.113                       | 0.113                    | 0                        | 0                          |
|                   | -Production quality  | 0.212   | 1.363                              | 0.143                         | 0.081                       | 0.081                    | 0                        | 0                          |
|                   | -System availability | 0.261   | 1.678                              | 0.170                         | 0.096                       | 0.096                    | 0                        | 0                          |
In Table 4 was depicted the scores result for six big losses of screw press machine on pressing station in term of productivity and sustainability for processing Crude Palm Oil Production (CPO) in company case study. Based Table 4, the percentages of the value rate of six big losses were setup and adjustment losses of 32.63%, equipment failure losses of 3.31%, reduced speed losses of 1.87%, idling and minor losses of 1.87%, reduced yield/scrap losses of 0%, and defect and rework losses of 0%. Sub-sequence, the weight value from the expert was multiplied by percentages of each six big losses. Figure 1 shows biggest losses among other losses that was the setup and adjustment losses, higher score contribution on technology of 11.779, was followed by economic of 8.614 (Figure 2). The lowest score was awarded by socio-political of 1.403.

Meanwhile, the highest scores for losses contribution on Overall Environmental Equipment Effectiveness (OEEE) i.e. sustainability, performance efficiency, production quality and system availability in productivity was awarded by performance efficiency on Technological of 4.076, followed by performance efficiency on Economic of 3.463, whilst, by performance efficiency on environmental of 1.408. Therefore, it is needed the technology, economic and environmental approaches to eliminate waste to improve performance efficiency for the pressing machines line of CPO in the case study company. The environmentally friendly technology can be alternative for
eliminate the setup and adjustment losses of the screw presses machine on pressing line of CPO process manufacturing. The company may adoption the lean manufacturing tools and techniques such as Automisation and Total Productive Maintenance. However, it is need to be analyzed for decision making on the optimization of the alternative between the views of environmentally friendly technological and the economic views, whether it will be appropriate to put into action.

4. Conclusion
This paper aims to develop a framework to assess the implementation of Overall Equipment Effectiveness (OEE) to eliminate waste for increased productivity, and to correlate with sustainability in the manufacturing industry. The framework consist of five steps: (1) Collect the OEE information data, (2) Identify the criteria and sub-criteria to be used in the framework model based OEE achievement in step 1 and it’s correlated to sustainable manufacturing, (3) Construct a hierarchically model based on the criteria and sub-criteria/alternatives identified at Step (2), (4) Determine the degree of importance, also known as weights of the criteria and sub- criteria/alternatives by using FAHP method and (5) Calculate and scoring of losses analysis to improve the productivity and sustainability in step (4), and then it is ranked to decide the priority. This framework was illustrated in line of screw press machine of a crude palm oil manufacturing company. The case study result revealed the highest scores for losses contribution on the OEE was awarded by performance efficiency on Technological of 4.076, Economic of 3.463 and environmental of 1.408. Further research can be developed the optimization method for feasibility implementation of the alternative between the views of environmentally friendly technological and the economic views in the case study company.

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