Analysis and mitigation of machine maintenance for sustainable industry

S Hamali1*, S Kurniawan2, D Y Setiawati3, Andy4, S Salim5

1,2,3,4,5Management Department, BINUS Business School Undergraduate Program, Bina Nusantara University, Jl. K.H. Syahdan No. 9, Palmerah, Jakarta 11480, Indonesia

Email: sambudi_hamali@binus.ac.id

Abstract. The manufacturing industry must maintain high productivity and quality to be competitive and sustainable. The best way to achieve this is through preventive maintenance programs. The aim of the research was to determine the effectiveness of engine performance, identify the constraints of the performance of a screw press machine, and determine preventive actions to minimize engine performance ineffectiveness. The research was conducted on Crude Palm Oil (CPO) production in Jambi Province. The analysis tools used are Overall Equipment Effectiveness (OEE), Fishbone Diagram, Failure Mode and Effect Analysis (FMEA), and 5-Whys analysis. The results show that OEE is still below world-class standards. The cause of screw press machine failure is the entry of foreign matter and wear from the machine. The most significant risk that has the potential to hamper the performance of the screw press is the loss of oil on the pulp or fiber and damage to components inside the screw press machine. Mitigation actions to minimize engine performance ineffectiveness are periodic maintenance, the application of preventive maintenance, and magnetic parts installation.

Keywords: machine maintenance, sustainable industry, preventive maintenance program

1. Introduction

In today's increasingly fierce competition, the manufacturing industry must meet the requirements of rapidly changing and diverse customers. The manufacturing industry must maintain high productivity and quality to be competitive and sustainable [1][2][3]. Damage to the machine is the most crucial thing for the manufacturing industry, where this can disrupt the company's performance. For a process to continue to produce the desired quality, machinery must be maintained in perfect condition. The best way to achieve this is through preventive maintenance programs. Many companies have moved to bring the concept of total quality management to preventive maintenance practices with an approach known as Total productive maintenance [4]. Total productive maintenance (TPM) is an innovative approach for equipment maintenance that involves maintenance personnel and operators working in teams that focus on eliminating equipment damage and equipment-related defects [5]. TPM is at least a proactive approach that aims to prevent any kind of negligence (slack) before it happens. The motto is "zero mistakes, zero work-related accidents, and zero losses" [6]. The TPM concept provides a quantitative metric called overall equipment
effectiveness (OEE) to measure each plant [7]. OEE is an indicator of overall equipment health and is the most commonly used equipment performance measure [5].

The research is carried out on Crude Palm Oil (CPO) production in Jambi Province. The company experiences a problem that is a decrease in product quality and finds issues in the production process, where one of the factors that caused it is the engine. Of the 15 machines used in the production process, screw press machines often experience breakdowns or damage, thus it gives impact on yields and production quantities. The screw press is a palm oil processing machine that functions to separate fiber, oil, and palm kernel. As a result of damage from the engine, total CPO production experiences instability and tends not to increase every month, so the company must repair or replace the components of the screw press machine. It is necessary to analyze the performance of the screw press and find the causes of damage and mitigation to minimize the ineffectiveness of engine performance in the future.

Based on previous research, there are several methods to overcome the problem of downtime, including [8], which says that downtime, breakdown, setup, and adjustment can result in decreased company productivity. In overcoming their problems, they use Overall Equipment Effectiveness to find out the engine performance and Fishbone diagrams to find out the cause of the issues they are facing.

Research conducted by [9], where the problem faced is in the form of poor welding quality. To overcome this problem, they use the Failure Mode and Effect Analysis method to analyze the risk of failure mode based on the risk rating scale. The results of the study stated that it can know and identify the causes of machine failures, and can understand the shortcomings arising from Magnetic force welding machines.

Research conducted by [10], where the problem faced is losing speed in the manufacturing industry (XYZ Corporation). To overcome these problems, they use 5-Whys analysis to determine preventive actions so that losses do not occur, as well as Fishbone diagram analysis to identify the factors causing problems and to stop the damage.

The difference of the research with the previous ones in overcoming the problems faced by the company is that the research combines four methods, namely, overall equipment effectiveness, fishbone diagrams, failure mode and effect analysis, and 5-Whys analysis. Therefore, the aim of the research is to determine the level of efficiency of engine performance, find out the most significant causes and risks that have the potential to hinder the effectiveness of engine performance, and to find out preventive actions to minimize the ineffectiveness of screw press machine performance.

2. Method

The research is conducted on Crude Palm Oil (CPO) production in Jambi Province. It is conducted from January to June 2019. Data analysis methods uses the calculation of Overall Equipment Effectiveness (OEE), Fishbone Diagrams, Failure Mode and Effect Analysis (FMEA), and 5-Whys Analysis. Data collection techniques are conducted by interviews with factory leaders and several division heads as the head of the company's operational division for Fish Bone analysis and 5-Whys Analysis, distributing questionnaires to the section head, and field mechanics involved in the Failure Mode and Effect Analysis (FMEA).

To answer the aim of the research, these steps taken are:
1. Calculate the OEE value to find out the performance of a screw press machine and compare it with the OEE world-class standard values;
2. Look for the causes of the constraints of the performance of the screw press machine with Fish Bone analysis and rank the most significant risks that could potentially hamper the effectiveness of the screw press machine performance with FMEA;
3. Knowing preventive actions to minimize the ineffectiveness of screw press machine performance with 5-Whys Analysis.
2.1 Calculation of Overall Equipment Effectiveness (OEE)

In OEE calculation, there are three indicators to determine the level of engine performance, namely:
1. Availability calculation,
2. Performance calculation, and
3. Quality calculation.

The formulation of OEE [11]:

\[
OEE = \frac{\text{Availability} \times \text{Rate} \times \text{Quality}}{100}
\]

Availability = \frac{\text{Available Time} - \text{All Recorded Downtime}}{\text{Available Time}}

Rate = \frac{\text{(Ideal Speed) x (Actual Speed)}^{\text{(Reduced Speed)}}}{\text{Ideal Speed}} \times \frac{\text{Processed Amount}}{\text{Reported Production Time} \times \text{Actual Speed}}

Quality = \frac{\text{Good Output Produced}}{\text{Processed Amount}}

2.2 Fishbone diagram analysis

Fishbone diagrams explain the factors that cause engine performance constraints, including Manpower, Machines, Methods, and Materials [4]. These problems significantly affect the company's operations.

Figure 1. Fishbone Diagram
The research conducts interviews to find out the root causes and sources of problems, they are the head of the factory, head of the production, assistant supervisor, head of the seed mill, chief of mechanics, mechanical helper, mechanical foreman, and mechanic.

2.3. Failure Mode and Effects (FMEA) analysis
FMEA is useful for identifying and filtering out potential failures that can occur when doing a project. At the end of the project, FMEA can document the status of the project, as a reference for the action plan, and record any improvements needed by the upcoming process. General steps for carrying out FMEA are [12]:

1. Analyze the process or product,
2. Identify potential failure modes,
3. List the potential effects for each failure mode,
4. Determine the severity rating (S) for the failure mode,
5. Determine the occurrence (O) rating for the failure mode,
6. Determine the detection rating (D) for failure mode,
7. Calculates the RPN for each failure mode,
8. Prioritize RPN,
9. Take action to eliminate or reduce high-risk Risk Priority Number (RPN)
10. , and
11. Calculates RPN results, when failure mode is reduced.

The FMEA worksheet is presented in Table 1.

Table 1. Failure Mode and Effect (FMEA) Worksheet

| Component and Function | Potential Failure Mode | Potential Effect (or) of Failure | S | O | D | SEV | OCC | DET | RPN | Recommended Actions | Person Responsible for Actions | Target Completion Date | Actions Taken | SEV | OCC | DET | RPN |
|------------------------|------------------------|----------------------------------|---|---|---|-----|-----|-----|-----|---------------------|-------------------------------|--------------------------|--------------|-----|-----|-----|-----|

Source: [12]
Risk Priority Number = Severity × Occurrence × Detection \hspace{1cm} (5)

Then the RPN value is arranged from the largest to the smallest value.

Before analyzing FMEA, it is necessary to test the validity and reliability of the questionnaire's results so that the data used as research material is valid and reliable. Validity and reliability tests were performed using SPSS version 23.

2.4. 5-Whys analysis
5-Whys analysis is a tool to solve problems. 5-Whys help identify the root of a problem or cause of a discrepancy in the production process, to find preventive actions to minimize the ineffectiveness of the production process [10]. The research conducts interviews with the general manager and several mechanics.

3. Result and discussion
3.1 Analysis of Overall Equipment Effectiveness (OEE)
There are three indicators to determine the OEE, those are:
1. Availability calculation to find out the percentage of engine readiness or availability in operation;
2. Performance calculation to determine the percentage of units of products produced by the engine in the available time;
3. Estimation of quality to know the percentage comparison of the number of units that are good with the number of units produced.

The data collected includes production log data for the period of July 2016 to December 2018 to get the results of the Overall Equipment Effectiveness calculation as presented in Table 2.
Table 2. Overall Equipment Effectiveness Calculation

| Year | Month     | Availability (%) | Rate (%) | Quality (%) | OEE    |
|------|-----------|------------------|----------|-------------|--------|
| 2016 | July      | 82.04%           | 79.75%   | 98.22%      | 64.26% |
|      | August    | 84.74%           | 80.70%   | 97.06%      | 66.37% |
|      | September | 87.41%           | 80.74%   | 97.59%      | 68.87% |
|      | October   | 86.04%           | 96.80%   | 98.02%      | 81.64% |
|      | November  | 84.57%           | 88.67%   | 98.43%      | 73.81% |
|      | December  | 86.46%           | 88.81%   | 98.42%      | 75.58% |
|      | January   | 85.54%           | 96.35%   | 97.96%      | 80.74% |
|      | February  | 83.01%           | 86.52%   | 98.62%      | 70.83% |
|      | March     | 87.56%           | 88.13%   | 97.66%      | 75.37% |
|      | April     | 86.39%           | 84.08%   | 97.65%      | 70.93% |
|      | May       | 81.28%           | 88.11%   | 97.51%      | 69.84% |
|      | June      | 77.64%           | 82.15%   | 95.29%      | 60.78% |
|      | July      | 84.57%           | 84.41%   | 96.86%      | 69.14% |
|      | August    | 88.75%           | 94.47%   | 98.05%      | 82.21% |
|      | September | 86.98%           | 91.09%   | 97.42%      | 77.18% |
|      | October   | 86.70%           | 90.22%   | 98.21%      | 76.83% |
|      | November  | 89.34%           | 94.30%   | 98.77%      | 83.22% |
|      | December  | 86.05%           | 92.69%   | 97.14%      | 77.48% |
| 2017 | January   | 77.56%           | 78.66%   | 94.96%      | 57.93% |
|      | February  | 86.24%           | 87.39%   | 97.49%      | 73.47% |
|      | March     | 88.22%           | 85.77%   | 98.02%      | 74.17% |
|      | April     | 82.69%           | 94.49%   | 97.75%      | 76.38% |
|      | May       | 81.73%           | 88.36%   | 96.68%      | 69.82% |
|      | June      | 85.80%           | 97.31%   | 98.60%      | 82.32% |
|      | July      | 87.68%           | 89.49%   | 97.66%      | 76.63% |
|      | August    | 86.52%           | 80.53%   | 98.26%      | 68.46% |
|      | September | 81.51%           | 77.73%   | 96.42%      | 61.09% |
|      | October   | 84.98%           | 94.11%   | 96.58%      | 77.24% |
|      | November  | 85.40%           | 99.10%   | 98.65%      | 83.48% |
|      | December  | 83.04%           | 84.26%   | 97.79%      | 68.42% |
|      | Average   | 84.88%           | 88.17%   | 97.59%      | 73.15% |

3.1.1 Availability
In Table 2, all Availability values do not reach world-class standards of 90% [6]. To analyze the availability distribution, the research uses a histogram, shown in Figure 2.
The average availability is 84.88 percent, with a minimum of 77.56 percent and a maximum of 89.34 percent, with no value above 90% as a world-class standard. With a value below world-class standards, this shows that availability has a large impact on OEE. According to [6], ways to increase the value of availability include reducing unplanned downtime, identifying and eliminating causes of decreasing availability, utilizing TPM and fast maintenance teams, and prioritizing preventive maintenance.

3.1.2. Rate
In Table 2, the average rate does not reach world-class standards of 95% [6]. To analyze the Rate distribution, the research uses a histogram as presented in Figure 3.

The average rate is 88.17 percent, with a minimum of 77.73 percent and a maximum of 99.10 percent. There are four values above 95% as world-class standards. This shows that the rate also has a significant impact on OEE, with an average value below world-class standards. According to [6], ways to increase the
rate value include determining appropriate resources to identify and close gaps, identify and close operational imbalances with the proper operator or process flow, and standardize operations.

3.1.3. Quality

In Table 2, all Quality scores do not reach world class standards of 99% [6]. To analyze the Rate distribution the research uses a histogram, presented in Figure 4.

![Histogram of the Percentage Quality](image)

**Figure 4.** Histogram of the Percentage Quality

The average quality is 97.59 percent, with a minimum of 94.96 percent and a maximum of 98.77 percent, there is no value above 99% as a world-class standard. With an average value below world-class standards, this also shows that quality has a significant impact on OEE. According to [6], ways to improve quality values include identifying, measuring, and enhancing scrap and rework, identifying problem areas, and installing error checks.

3.1.4. OEE

The average OEE results from July 2016 to December 2018 are 73.15%; it does not meet the world-class standard, which is 85% [6]. So, improvements are needed to reach a world-class standard. Based on surveys conducted around the world, for the manufacturing industry, the average OEE was above 65% [13], while the results of research [14] in the Swedish manufacturing industry that the average OEE was 51.5%. The low value of OEE in this study can be further analyzed through fishbone diagrams, FMEA, and mitigation actions with 5-Whys Analysis.

3.2. Fishbone diagram analysis

According to [8], Fishbone Diagram, also known as the Ishikawa diagram or fishbone chart, is a tool to identify quality problems in a product. Illustration of a graph that resembles a fishbone shape that will represent the possible source of error. There are four categories in fishbone diagrams, namely: material, machinery or equipment, energy, and methods. These four categories are causes and can provide initial analysis, as of Figure 5.
3.2.1. Man
Based on the results of analysis and data, man's constraints are caused by a lack of human resources, lack of education - The minimum level of knowledge and understanding of the standards imposed by the company, and negligence of workers.

3.2.2. Machine
Based on analysis and data, machine constraints are caused by the first the entering of foreign components and wear machine, such as iron, wood entering the engine, would significantly disrupt its production activities and damage the elements contained in the screw press. Second wear machine could be overcome for all the process that occurs in control. It is necessary to have periodic checks to anticipate wear and tear. Wear device can have a significant enough effect because it will cause losses so that the finished product is not optimal in quantity.

3.2.3. Material
Based on the results of analysis and data, material constraints are caused by the substandard quality of raw materials. Quality below standard is a condition where fresh fruit bunches are not mature enough to be processed into CPO.

3.2.4. Method
Based on the results of analysis and data, the method constraints caused by the first inhouse training are less effective. When companies conduct training on all workers, it is expected that all individuals involved will better understand, and the production process can run better. Second, the briefing is not maximal - Briefing is intended for all divisions, but there are times when the briefing is less effective due to human factors, as well as other factors.

3.3. Failure Mode and Effect Analysis
According to Kmenta in [15], FMEA is a systematic technique for finding, measuring, evaluating, and evaluating potential problems or failures from design to process before issues occur. Failure Mode and Effect Analysis is used to identify potential failures, namely by calculating the severity value, occurrence, and detection of the causes of failure by distributing questionnaires to the head of the section and also the

Figure 5. Fishbone Diagram Result
field mechanics with a total of 34 respondents, to give a rating on a scale of 1 to 10 for severity, occurrence, and detection. The value of this scale is useful to get the value of Risk Priority Number (RPN), then the value of the RPN is arranged from the largest to the smallest value. The biggest RPN value is the leading cause of the problems that occur.

Before analyzing FMEA, it is necessary to test the validity and reliability of the questionnaire's results so that the data used as research material are valid and reliable. Of the eight questions for severity, there are four invalid question items, namely Question (Q) 3, Q6, Q7, and Q8, so that this question is discarded and not included for subsequent analysis. Furthermore, the validity and reliability tests of the results of the occurrence and detection questionnaires for Q1, Q2, Q4, and Q5 are all valid and reliable. After the validity and reliability tests have been completed, it can proceed to the next stage, namely the calculation of the RPN from each failure mode, as presented in Table 3.

### Table 3. RPN Calculation

| Process                                    | S  | Potential Failure Mode       | O  | Potential Failure Effects                | D  | RPN |
|--------------------------------------------|----|------------------------------|----|-----------------------------------------|----|-----|
| Separation of fruit                        | 9  | Engine wear & tear           | 4  | Loss of oil in the pulp and fiber       | 3  | 108 |
| The process of separation between fiber, oil and palm kernel | 9  | Screw press which is entered by iron | 4  | Broken component in the screw press machine | 3  | 108 |
| Pressing of FFB                            | 10 | Fiber press pressure weakens  | 3  | Some of oil is followed to be filtered with fiber so that the company suffers losses | 3  | 90  |
| Boiling Fresh Fruit Bunches (FFB)          | 10 | The temperature when boiling is not appropriate | 3  | Separation of fiber with oil is not optimal | 2  | 60  |

Table 3 shows which process has the highest RPN value, then sorted from the largest to the smallest. So, the risks that potentially hinder the effectiveness of screw press performance are loss of oil in the pulp and fiber, and broken component in the screw press machine.

### 3.4. 5-Whys analysis

According to [10], by asking the question "Why" one can separate the symptoms from the cause of the problem. This is very important because symptoms often cover the cause of the problem. Use of analytical techniques 5-Whys effective will determine the root causes of nonconformities and then lead the organization to develop effective long-term corrective and preventive actions. Prevention actions using 5Whys Analysis relate to the risk or failure effect of the FMEA in Table 3 with the highest RPN value; this method helps by finding the root cause of the problem. The research conducts interviews with the general manager and several mechanics in the 5-whys analysis. Below is a 5Whys analysis table to find the causes of each risk from RPN calculations. The results can be seen in Table 4.
Table 4. 5-Whys Analysis

| Risk                                      | Why 1 | Why 2 | Why 3                                      | Why 4                          | Why 5                           |
|-------------------------------------------|-------|-------|--------------------------------------------|-------------------------------|---------------------------------|
| Loss of oil in the pulp and fiber         | Engine wear & tear | The machine is old or worn | The machine is used more than the specified limit | Worker's insensitivity         |
| The broken component in the screw press machine | Screw press which is entered by iron | The magnet does not maximally pull the iron component | Magnets are stuck or bound to FFB | Checking process is less carefully | Negligence of workers |

Table 4 shows that each risk originating from the RPN calculation has its root cause. Furthermore, the Table 5 explains what mitigation strategies and actions companies should implement to prevent each risk.

Table 5. Mitigation Actions

| No | Risk                                      | Mitigation Strategy                          | Description                                                                 |
|----|-------------------------------------------|----------------------------------------------|-----------------------------------------------------------------------------|
| 1  | Loss of oil in the pulp or fiber          | Periodic maintenance and the application of preventive maintenance | 1. Apply scheduled maintenance to the machine to minimize damage.  
2. Make a detailed record of preventive maintenance.  
3. Give briefings to workers. |
| 2  | The broken component in the screw press machine | Installation of magnetic components | 1. Increase the installation of magnetic components in the machine before a screw press processes FFB. The external element that makes the component in the screw press broken is iron, while the magnet is an object that can attract the metal so it must minimize the engine's entry of foreign objects.  
2. Implement preventive maintenance. Besides that, it is necessary to keep records so that they do not exceed the specified limits. |

So, to answer the last research objective, the recommended mitigation actions are periodic maintenance, the application of preventive maintenance, and the installation of magnetic components. Based on the company's acknowledgment, after they implemented some of our recommendations, including the installation of magnetic components, added, as well as additional checking hours on Saturdays, their production increased by an average of 10% per month.

4. Conclusion
The average OEE value is still below world-class standards based on the results and analysis of data from July 2016 to December 2018. Factors that cause constraints from the performance of the screw press machine are humans, machines, raw materials, and methods. The risks that potentially hinder the effectiveness of screw press performance are loss of oil in the pulp and fiber, and broken components in the screw press machine. The mitigation actions to prevent potential failures are periodic maintenance, the application of preventive maintenance, and the installation of magnetic components. Based on the company's recognition, by carrying out mitigation actions, the company's average production increases by
10 percent per month. This shows that preventive maintenance programs can improve company performance and to build a sustainable industry, especially the CPO industry.

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