Failure Mode and Effect Analysis (Fuzzy FMEA) Implementation for Forklift Risk Management in Manufacturing Company PT.XYZ

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Abstract. Company improvements and evaluations must always be carried out by companies to improve company performances. One of the factors that influence the performance was the smooth production on machine performance. Good risk management was one of the keys to maintaining a smooth production process. This research was conducted at a manufacturing company, PT. XYZ, to carry out risk management on machines that had low performance. From the results of the quarterly report to the four parts of maintenance, the forklift was a machine and facility with the lowest NPM (Quality Performance Score-QPS). The method used in this research was Fuzzy FMEA (Failure Mode and Effect Analysis), in order to obtain priority in repair and maintenance of forklifts. The result of this study was that the failure mode of the hydraulic hose rupture got the highest FRPN (Fuzzy RPN) value of 631 so that the hydraulic part with the failure mode of the broken hydraulic hose was recommended to be the main focus in the repair and maintenance of the forklift. The result of using Fuzzy FMEA was more proposed as a reference focus to get more objective risk management compared to conventional FMEA results in machine repair and maintenance.

Keywords: Risk Management, Forklift, Fuzzy FMEA, Maintenance Priority

1. Introduction

Manufacturing company would need a robust system to conduct improvement and evaluation in order to elevate the performance. The performance could be determined by the continuity and smoothness of the production process and machine performance [1]. In order to create a smooth process in the production process, a good risk management process was needed in solving the problem of machine damage or production equipment [2]. The amount of investment costs in purchasing machinery forced the company to try to maintain and repair the engine so that the machine can work optimally. Therefore, there was a need for risk management in this manufacturing company. Risk management is an approach that is carried out on risk by understanding, identifying and evaluating risks, then considering what will be done to the impacts that arise and reducing the risks that occur [3]. The purpose of risk management is to recognize the risks that can occur and develop strategies to reduce or even avoid them [4]. With good risk management, the company can minimize or even avoid risks that might occur so that the company's productivity will be elevated. PT. XYZ is a state-owned railway production industry that used a variety of machines and tools to produce train ordered and for the maintenance of the train itself.
According to the fourth quarterly report on maintenance, the forklift is a machine and production support facility with the lowest NPM (Value of Quality Performance/Quality Performance Score) value. Forklifts functioned as transportation and a device that could lift items [5]. Some factors that cause damage to forklifts are due to human error, the age of the old forklift, the capacity of the workload that exceeds the capacity of the forklift itself and the equipment used continuously. Based on these problems, a risk analysis of the damage that caused the broken forklift was made to be the focus of the proposed improvements in minimizing the risks to the train production process. The method chosen in this study was Fuzzy FMEA (Failure Mode and Effect analysis) rather than conventional FMEA. Conventional FMEA has several weaknesses which will give less accurate and vague results. Some weaknesses in conventional FMEA are explained in the next chapter. The difference in the results of risk management between conventional FMEA and Fuzzy FMEA will be presented and explained in the results and discussion chapter. It was as a confirmation in proving that Fuzzy FMEA was an accurate method to be used in risk management for forklifts at PT. XYZ.

2. Methods

2.1. FMEA (Failure Mode and Effect Analysis)

FMEA is a systematic method in identifying and preventing problems that occurred in products and processes [6]. The output of this method is RPN (Risk Priority Number). The RPN is a reference to provide recommendations to be used as a focus of maintenance and improvement from the biggest types of risk occurred based on its priorities, in this case the risk of the biggest failure that occurred was on the forklift. To obtain the score of RPN value, it was necessary to have input in the form of severity (S), occurrence (O) and detection (D) values. Severity is the value of the severity of the consequences that would lead to the continuation of the next process which also indirectly is detrimental; meanwhile, the occurrence is the value of how often the possible causes of failure occurred; furthermore, the detection is the value of how far the cause of failure can occur [7]. The assessment is carried out by the expert. Regarding the severity (S) there were 10 ranks with the description of the effects and criteria for each ranking. Ranking 1 means that it has no effect and is indicated by the criteria that does not result in anything. Whereas in rank 10 had dangerous effects without warning and has the criteria in the form of a machine that was not feasible to operate, because it could cause a sudden accidents and was contrary to occupational safety regulations [8]. On the other hand, at the value of occurrence (O) had 5 ranks with the presence of an explanation in the form of the probability of occurrence and the cause of failure and the probability of failure in each ranking. Ranking 1 showed if the chance of occurrence was very small with no failure associated with the process and the probability of failure was 1 in 1,500,000. Whereas rank 5 showed the probability of occurrence that was very high with failure almost unavoidable and the probability of failure was 1 in 2 [8]. Moreover, in detection (D) there were 10 ranks where each ranking could explain the detection group and its criteria. Ranking 1 was included in the detection group on almost certain with the criteria in the form of control almost certainly could detect failure. Whereas in the 10th rank included in the detection group Absolutely impossible with no control criteria to detect failure [8].

2.2. Fuzzy FMEA

Fuzzy logic was one method for analysing systems that involving uncertainties [9]. Research using Fuzzy logic would get more accurate results compared to using conventional FMEA methods [10]. According to [11] and [12], some Conventional FMEA weaknesses are:

1) Statements in FMEA were often subjective and qualitative explained in natural language.
2) Three levels of severity (S), occurrence (O) and detection (D) parameters that were assumed to have the same interests, it turned out that in practice the importance of the three parameters was not the same.
3) The same value of risk priority number (RPN) resulting from the multiplication of S, O and D levels may imply a different risk representation.
To overcome these weaknesses, methods based on Fuzzy logic were often used to manipulate linguistic terms that are used directly in making critical judgments. The process stages of the Fuzzy FMEA are described below:

1) Fuzzyfication, was a defining moment of membership functions and Fuzzy sets of severity, occurrence, detection and Fuzzy RPN (FRPN).

2) Evaluation of Fuzzy Rule, using IF-THEN rule where IF was a variable of Fuzzy input while THEN was a variable of Fuzzy output. All combinations must be grouped to produce Fuzzy rules. For example: IF Severity was Very High, And Occurrence was Very High, and Detection was Very High, THEN FRPN was Very High.

3) Defuzzyfication, with input defuzzyfication that was the Fuzzy set obtained from the composition of Fuzzy rules, while the output was the number in the Fuzzy set [9]. The technique used in this study was the Centre of Gravity (Centroid), which was the score value of the output obtained based on the centre of gravity of the decision making process. In this study, defuzzyfication was used to find the output value in the form of FRPN value based on the input that had been defined.

For conventional FMEA, risk failure assessment was obtained by multiplying the value of severity, occurrence and detection. However, conventional FMEA did not pay attention to the importance of each input, so that in its calculation each input had the same level of importance. In addition, the assessment was subjective and qualitative, and also the RPN value was obtained only from the results of the third time input. Therefore, the severity, occurrence and detection values were assessed using Fuzzy Logic with the Mamdani (Min-Max) method to get the FRPN (Fuzzy Risk Priority Number) value [7]. The following was a table of number index categories for severity, occurrence, detection, and membership function parameters for input and output variables (Table 1., Table 2., Table 3. and Table 4.)

| Score | Category |
|-------|----------|
| S     | O        | D        |
| 1     | 1        | 1        | VL       |
| 2.3   | 2.3      | 2.3      | L        |
| 4.5, 6| 4.5, 6   | 4.5, 6   | M        |
| 7, 8  | 7, 8     | 7, 8     | H        |
| 9, 10 | 9, 10    | 9, 10    | VH       |

| Category | Curve Types | Parameter |
|----------|-------------|-----------|
| VL       | Trapezoid   | [0 0 1 2.5] |
| L        | Triangle    | [1 2.5 4.5] |
| M        | Trapezoid   | [2.5 4.5 5.5 7.5] |
| H        | Triangle    | [5.5 7.5 9] |
| VH       | Trapezoid   | [7.5 9 10 10] |
Table 3. Parameters of Membership Functions of Output Variables [7]

| Category | Curve Types | Parameter |
|----------|-------------|-----------|
| VL       | Trapezoid   | [0 0 25 75] |
| VL – L   | Triangle    | [25 75 125] |
| L        | Triangle    | [75 125 200] |
| L – M    | Triangle    | [125 200 300] |
| M        | Triangle    | [200 300 400] |
| M – H    | Triangle    | [300 400 500] |
| H        | Triangle    | [400 500 700] |
| H – VH   | Triangle    | [500 700 900] |
| VH       | Trapezoid   | [700 900 1000 1000] |

Research data was obtained on 3-tons and 5-tons capacity forklifts to determine the RPN value of each type of damage. Assessment of severity (S), occurrence (O) and detection (D) was carried out by expert forklifts because there was not enough data on risk factors and uncertainty factors. In general, Microsoft Excel 2013 software was used as an instrument in processing research data. However, there was a specific instrument, Fuzzy Logic Toolbox, which is a MATLAB software program that was specifically used to calculate the RPN value on Fuzzy FMEA.

3. Results and Discussions

After observation, there are 12 failure modes categorized according to the appropriate equipment on the forklift carried out by the expert. FMEA assessment result is shown in the following table (Table 4.).

Table 4. FMEA Assessment Results

| No | Equipment | Function | Functional Failure | Failure Mode | Effect of Failure | S  | O  | D  | RPN |
|----|-----------|----------|--------------------|--------------|------------------|----|----|----|-----|
| 1  | Clutch pad| To channel power from the engine to the transmission | Power is not achieved | Wear clutch pads | Forklifts are not road / road but lack power | 8  | 1  | 6  | 480 |
| 2  | Master clutch | Push hydraulic oil to release clutch pads from Clutch pads on flywheel | not release from flywheel | The piston master clutch wears out and the master clutch seal was broken | Gear did not want to be inserted | 8  | 1  | 5  | 400 |
| 3  | Radiator  | Maintain the engine working temperature | The temperature was not maintained according to the radiator | The radiator water is dirty, the radiator | Engine was overheat and does not start | 8  | 3  | 5  | 120 |
| No | Equipment | Function          | Failure Mode     | Effect of Failure                             |
|----|-----------|-------------------|------------------|-----------------------------------------------|
| 1  | System    | Worked at temperature | was rusted       | Component damage in the engine                |
| 2  | Sub-system | Clutch tubes, Master clutches, Radiators, Tires, Solar Tanks, Hydraulic, Starters Motor | |
| 3  | Sub-system function | | | |
| 4  | Tires     | As a driving forklift | Tire leaking | Forklift was not moving                      |
| 5  | Solar tank | Solar Container | Forklift jam | Fuel pump damaged / Bosch pump                |
| 6  | Hydraulic | Load Lifting | Unable to lift weights at capacity | Leaking Seal hydraulic | The fork drive power was |
Based on the results of conventional FMEA calculation, the largest RPN value was in the failure mode of wore clutch with an RPN value of 480. In the S, O and D assessment using conventional FMEA, RPN was obtained from the results of the three multiplication of inputs without regard to the importance rating of each input. Whereas in Fuzzy FMEA the RPN results were obtained by paying attention to the degree of importance (degree of membership in Fuzzy Logic) from each input. The following were the priority results of Conventional FMEA and Fuzzy FMEA (Table 5).

### Table 5. Priority Results of Conventional FMEA and Fuzzy FMEA

| No | Failure Mode                                           | RPN | Category | Priority | Fuzzy RPN | Category   | Priority |
|----|--------------------------------------------------------|-----|----------|----------|-----------|------------|----------|
| 1  | Hydraulic hose breaks                                  | 448 | High     | 2        | 631       | High – Very High | 1        |
| 2  | Wear clutch                                            | 480 | High     | 1        | 630       | High – Very High | 2        |
| 3  | The piston and the master clutch seal were wore and damaged | 400 | Medium – High | 3     | 613       | High – Very High | 3        |
| 4  | The Solar filters were clogged/dirty, diesel tanks were dirty/many deposits, clogged fuel pumps | 336 | Medium | 4        | 534       | High       | 4        |
| 5  | Overload                                               | 125 | Low      | 8        | 533       | High       | 5        |
| 6  | The field were too many plates and operator was not having full attention | 240 | Low – Medium | 5     | 489       | High       | 6        |
| 7  | The radiator water was dirty, the radiator was rusty   | 120 | Low      | 9        | 439       | Medium – High | 7        |
| 8  | The radiator grille was leaky                          | 120 | Low      | 10       | 439       | Medium – High | 8        |
| 9  | Broken hose radiator                                   | 120 | Low      | 11       | 439       | Medium – High | 9        |
| 10 | Carbon brush motor starter was used up.                | 96  | Very Low | 12       | 428       | Medium – High | 10       |
| 11 | Leak hydraulics seal                                   | 210 | Low – Medium | 6     | 407       | Medium – High | 11       |
| 12 | Electric current less than voltage working(12 V)        | 128 | Low      | 7        | 261       | Medium       | 12       |
In Conventional FMEA calculations, wear coupling pads had the highest RPN value of 480, while the broken hydraulic hose had the second highest RPN value of 448. In the calculation using Fuzzy FMEA, the highest RPN value was the broken hydraulic hose, as 631, while the wear clutch had the second highest RPN value as 630. The difference in results was due to the calculations using Conventional FMEA only multiplying the value of S (severity), O (occurrence) and D (detection) without regard to the importance of each input. This is due to its use only in linguistic terms in determining the S (severity scores), O (occurrence) and D (detection) in conventional FMEA [14]. Conventional FMEA only looked at the RPN value and treats risk factors in the same level of importance without calculating the relative importance of these risk factors [15]. In conventional FMEA the assessment of failure factors applied to natural language will obtain ambiguous and vague information [12]. Whereas with Fuzzy FMEA the value was generated by observing the importance of each input obtained from the results of processing Fuzzy. Based on these results, it can be concluded that the focus of attention in the maintenance and repair of the forklift was the hydraulic part with failure mode identified was the broken hydraulic hose. This was due to the failure mode has a high damage intensity, high severity, detection of the failure was tended to be difficult to detect with a high degree of importance based on the results of Fuzzy processing. Doing maintenance and repair certainly requires a lot of time and money. This priority was given as a way out to prevent damage that may occur on the forklift with limited costs as well as to speed up the process of handling forklift damage [13].

Hydraulic systems are important to be noted because they have an important contribution in lifting the load to be lifted by the forklift [16]. The hydraulic system determines the lifting weight of the forklift [17]. Lifting strength also affects the fork speed of the forklift in load and unload loads or goods. The lifting speed of the fork load on the forklift must be as minimal as possible in the lifting process or must be subtler in lifting the load which is sometimes ignored by the operator to achieve high performance. In this case, the hydraulic system also takes an important contribution to the forklift power control [18]. By knowing the biggest risk priority, it can be used as a focus in subsequent preventive maintenance on the forklift.

4. Conclusions and Recommendation

4.1. Conclusions
Based on the results of calculations using Fuzzy FMEA, the first priority scale that was used as the focus of maintenance and repair on the forklift was the hydraulic part with the failure mode identified was the broken hydraulic hose. This rupture of the hydraulic hose caused the power fork drive to decrease or even the hydraulic could not be functioning. Furthermore, this failure mode had a FRPN value of 631. The results using Fuzzy FMEA were more proposed as the reference focus for repair and maintenance due to the results pay attention to the importance of each input so that the results were more objective compared to the results of Conventional FMEA.

4.2. Recommendations
For further research, the recommendation is to conduct a deeper study of which should be the main focus between FMEA Conventional or Fuzzy FMEA in the application of risk analysis. Furthermore, it is expected to be able to use the integration of Fuzzy FMEA methods with other methods so that the results of the analysis of the risks that may occur can be more accurate.

5. References

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