Root Cause Analysis of Fires in Coal Power Plants Using RFMEA Methods

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Abstract-Fire is one of the highest risks in using coal as fuel for electricity generation. Coal fires often occur in the area of coal handling facilities and are caused by equipment damage, accumulation of coal dust that has not been cleaned and burning coal itself. This study aims to find out how the application of the RFMEA (Risk Failure Mode Effect Analysis) method for the analysis of the root causes of fires in the Pacitan Coal Fired Power Plant case study uses a quantitative approach to find the root causes of prevention by respondents from PT. PJB UBJOM Pacitan at manager and supervisor level. In implementing RFMEA, the severity, events, and detection are needed to produce risk level figures which will be used as a step in determining the priorities of the company's mitigation management. Based on this study, 15 types of equipment failures were found at the operational coal handling facility at PT PJB UBJOM PACITAN. By using the RFMEA method, 1 type of critical failure can be found that requires more attention from management to mitigate the risk immediately, namely dust on coal both from barges and coal yards with risk value 32.05.

1. Introduction
The Coal Handling facility at the coal-fired power plant is a major system used to handle coal from receiving coal from shipping ships from coal mines and then transferring it to the coal yard for use as a storage place for coal reserves. Which is then transferred to the bunker area as a boiler fuel. The coal used as a fuel for Pacitan Coal Fired power plant with a capacity of 2 x 315 MW is coal with Low Rank Coal type, where this coal has special characteristics that are easily deformed, dusty and self-combustion.

So that in operating a steam power plant using coal of Low Rank Coal type, the company must carry out extra strict supervision of the handling of coal dust and combustion itself to ensure the power plant operational processes in generating electricity can run safely and avoid fires. Fires in coal-fired power stations can be caused by equipment damage and accumulation of coal dust that has not been cleaned, which can cause self-ignition. In an effort to analyze, evaluate and reduce the potential for a fire to occur in a coal-fired power plant, an operational analysis of the equipment in the Coal Handling Facility must be carried out.

The operational analysis of equipment in the Coal Handling Facility can be done by conducting a risk assessment using a comprehensive risk management system used by the organization for the purpose of increasing the value of the company. Implementing appropriate risk management will have
a major impact on all areas of work from operations, maintenance, and engineering. Risk analysis is a series of processes carried out with the aim of measuring risk and evaluating risk. The purpose of risk evaluation is to understand the characteristics of risk so that risk will be more easily controlled [1]. The application of risk analysis in this case uses FMEA and RFMEA to find out the most critical risks in order to prevent the operational failure of the Coal Handling Facility that can cause a fire.

2. Basic Theory and Methodology

2.1. FMEA

FMEA is a method designed for [2]:

- Fully identify and understand the potential failure modes and their causes, and the effects of failures on the system or end users, for a particular product or process.
- Assess the risks associated with the modes, effects, and causes of failure identified, and prioritize problems for corrective action. Identify and take corrective actions to address the most serious problems.

The FMEA standard requires Severity (Sev), Occurrence (Occ), and Detection (Det) values, multiplication of the three values will result in a Risk Priority Number (RPN) value. Failure and effect analysis (FMEA) modes have long been used as a planning tool during the development of processes, products, and services. In developing FMEA, the team identified failure modes and actions that could reduce or eliminate the occurrence of potential failures. FMEA analysis involves a diverse team of people from different backgrounds (e.g. mechanics, instruments, electricity, and operations) with the brainstorming method, because this increases the likelihood that all failures will be identified and their effects will be estimated correctly. [3] The use of the FMEA method is used as a method to identify error modes, to assess the consequences of specific damage and to subjectively conclude risks and number of priorities.

2.2 RFMEA

Risk Failure Mode and Effects Analysis (RFMEA) is the development or modification of the FMEA format to be more focused in finding critical risks. The addition of the risk score value which is then deducted from the Risk Priority Number will get a critical risk in accordance with what is expected in this study. The FMEA standard requires Occurrence, Severity and Detection values, multiplication of the three values will result in a Risk Priority Number (RPN) value. With this RFMEA format added risk score values, namely the multiplication between Likelihood and Impact [4].

2.3 Project Risk Management Using the FMEA Project Risk

In the paper [5] in 2004 has done research by modifying the FMEA format into the Risk FMEA format. Taking the background of the electronics industry, a search for the most critical processes in making an electronic device is carried out. From the value that already exists in the FMEA format, another value is inserted into the risk management concept. Simply modify the RFMEA form as shown in Table 1 below.

| Table 1. RFMEA format [5] |
|---------------------------|
| Typecal FMEA Columns      | Failure ID | Failure Mode | Occurrence | Severity | Detection | RPN |
| Typecal RFMEA Columns     | Risk ID    | Risk Event   | Likelihood | Impact   | Risk Score | Detection | RPN |
2.4 Methodology
The stages planned in this study are divided into several sections, namely:

![Figure 1. Research Stages](image)

3. Results and Discussion

3.1 Risk Identification
This study uses the RFMEA method through a quantitative approach with in-depth interviews. The study was conducted at PT. PJB PACITAN UBJOM with data for the period 2018 - May 2020. Interview respondents in this study were employees of PT. PJB PACITAN PJB with Manager and Supervisor level and CHF experts who have the task of handling operations and maintenance in the Coal Handling Facility and found 15 respondents who meet these requirements.

3.1.1. Rating Value
Rating using a scale of 1 to 5 with a description of conditions such as in Table 2 below.

| Severity Scale | Occurrence Scale | Rating |
|----------------|------------------|--------|
| Not significant | Very small       | 1      |
| Minor           | Small            | 2      |
| Medium          | Is               | 3      |
| Significant     | Big              | 4      |
| Havoc           | Very large       | 5      |

3.1.2. Review of RPN and Risk Level
RPN or Risk Priority Number is analyzed using Pareto diagrams. With analysis, this will get risks that fall into the critical category based on the RPN value. Ranking of RPN results is done simply by considering severity first, then followed by occurrence [6]. To find out the level of risk is determined based on the risk matrix. Research variables included in the critical category based on the RPN and the level of risk with a High Risk and Moderate level are concluded to be critical risks for the operational failure of the Coal Handling Facility.
3.2 Mitigation Plan

At this stage a Focus Group Discussion is conducted to obtain a mitigation plan as a risk response plan for known critical risks. Basically, there are two strategies to reduce risk, the first is to reduce the likelihood of these events and/or reduce the impact of these events [7].

From the K3 field history data of PT. PACITAN UBJOM PJB which shows that there have been 192 events self-combustion/fire that occurred in the Pacitan power plant in the period 2018 - April 2020 which is shown in Figure 2. This graph illustrates that the importance of immediate risk measurement and mitigation to prevent self-combustion in the coal handling facility area.

![Figure 2. Historical self-combustion / fire graph at CHF Pacitan power plant](image)

Based on book [8] this is used as a reference to determine the operational failure variable categories in the coal handling facility. Below this is the category of variables used in this study by following the subsystem classification from previous research:

- Failure in Coal
- Failure on the Conveyor system
- Failure on the Tower Transfer
- Failure in Coal Yard
- Bunker / Silo Failure
- Failure of the Dust Collector System
- Failure of the Dust Suppression system
- Failure on the Permit system
- Failure of Housekeeping

3.3 Data Processing and Analysis

Focus Group Discussion (FGD) is carried out to verify the failure mode followed by structural position holders in the Power Plant who are also expert speakers on the ins and outs of the CFPP's operations, especially in the area of coal handling facilities. PT. PJB has used Occurrence and Severity to map risk with the risk matrix analysis method according to Table 3 and Table 4.
### Table 3. Rating Occurrence

| Rating | Descriptor | Descriptions |
|--------|------------|--------------|
| 1      | Very small | Almost certainly nothing will happen |
| 2      | Small      | Small chance will happen |
| 3      | Is         | it is likely that the same will happen and does not occur |
| 4      | Big        | Most likely will happen |
| 5      | Very large | Almost certainly will happen |

### Table 4. Severity Rating Values

| Rating | Descriptor | Health and safety | Asset Safety | Environment | Reputation | Electric Power Supply |
|--------|------------|-------------------|--------------|-------------|------------|-----------------------|
| 1      | Not significant | There were no casualties. | Asset damage can be repaired with FLM and PM. | No warning from KLH. | Impact not that means, does not cause permanent operational disruption. | Down time to 3 hours. |
| 2      | Minor      | Victims of minor injuries (outpatient) | Minor asset damage | Reprimand from the Ministry of Environment | The minimum impact in the form of complaints or dissatisfaction, does not interfere with business operations. | Down time: 3 - 12 hours. |
| 3      | Medium     | Medium injury victim (hospitalization) | Asserting damage | Loud warning from KLH. | Complaints, dissatisfaction, demonstrations and media scrutiny trigger stakeholder responses, business operations are disrupted. | Down time: 12 hours - 1 day. |
| 4      | Significant| Victims of serious injury / permanent disability | Assets are heavily damaged, need repair. | Fines / operational restrictions from KLH | Broad media spotlight in the area, triggering a response from the government, business operations have stalled for some time, urgent handling is needed. | Down time: 1 day - 1 week. |
| 5      | Havoc      | Fatalities. The set is severely damaged, unable to be used again. | Location closure, or transfer by KLH. | | The national spotlight requires special government policies, threats to long-term businesses. | Down time > 1 week. |

Risk assessment at PT PJB UBJOM PACITAN currently only focuses on the value of the risk score as shown in the risk score matrix at PT PJB. As for the risk that receives special attention from management starts at a moderate risk (minimum risk score of 10) and management attention will be higher when the risk level is also higher. The matrix that shows the range of risk scores, risk level criteria and steps to be taken at PT PJB UBJOM PACITAN can be seen in Table 5.
Table 5. Range of Matrix Values and Their Meanings in PT PJB

| Value | Code | Meaning          | Information                                      |
|-------|------|------------------|--------------------------------------------------|
| 17-25 | E    | Extreme Risk     | Risk monitoring and mitigation by management requires support from the Head Office |
| 10-16 | T    | High risk        | Risk monitoring and mitigation by management    |
| 5 - 9 | M    | Moderate Risk    | Risk monitoring and mitigation by the Supervisor |
| 1 - 4 | R    | Low risk         | Risk monitoring and mitigation by related Users / operational implementers |

And to get the RFMEA value in this study according to paper [4] the value of rating detection uses the value according to Table 6.

Table 6. Rating Detection

| Rating | Criteria    | Information                                      |
|--------|-------------|--------------------------------------------------|
| 1      | Very High   | Interference will cause alarm or trigger shutdown |
| 2      | High        | Disturbances can be detected according to deviations |
| 3      | Low         | Interference not detected by sensor              |
| 4      | Remote      | Interference not physically detected             |
| 5      | Never       | Disturbances cannot be detected by any method    |

3.4 Critical risk

Then for the RPN value obtained through the distribution of questionnaires. A total of 15 credible respondents consist of personnel who every day carry out the monitoring and control functions of the coal handling facility namely the Coal Handling System Supervisor controls the Coal Handling system, Fuel Supervisor who evaluates coal handling, Maintenance Supervisor and Fire Engineer who are expert personnel in conducting the design and evaluation related to fire protection system. From the interviews, there were 15 types of failures in the coal handling facility area and RFMEA calculation values shown in Table 7.

Table 7. RFMEA Calculation Value

| CODE | TYPE FAILURE                | Occ | Sev | Det | Risk Score | RPN  | Rank | Risk Level |
|------|-----------------------------|-----|-----|-----|------------|------|------|------------|
| F1   | Coal is dusty               | 3.5 | 3.3 | 2.75| 11.66      | 32.05| 1    | High risk  |
| F2   | Self-combustion on the barge| 2.9 | 3.2 | 2.58| 9.256      | 23.88| 2    | Moderate Risk |
| F3   | Housekeeping not clean      | 2.3 | 2.7 | 2.58| 6.008      | 15.50| 11   | Moderate Risk |
| F4   | Self-combustion coal yard   | 2.9 | 3.1 | 2.5 | 8.994      | 22.48| 4    | Moderate Risk |
| F5   | Dust Collector System broken| 2   | 2.3 | 2.67| 4.66       | 12.44| 15   | Low risk   |
| F6   | Fire Protection system not standby | 2.3 | 2.2 | 2.5 | 5.056      | 12.64| 14   | Moderate Risk |
| F7   | Dust Suppression System broken| 1.9 | 3.5 | 2.67| 6.72       | 17.94| 10   | Moderate Risk |
| F8   | Hot Surfaces                | 2.6 | 2.8 | 3.08| 7.301      | 22.49| 3    | Moderate Risk |
| F9   | Mechanical Spark            | 2.1 | 3.3 | 2.67| 6.76       | 18.05| 9    | Moderate Risk |
| F10  | Hot work is not licensed    | 2.6 | 3.3 | 2.58| 8.385      | 21.63| 5    | Moderate Risk |
Based on data from Table 7, a Pareto diagram can be made to rank the RPN shown in Figure 3.

\[
\text{Critical Value RPN} = \frac{\text{Total RPN}}{\text{Total Risk}} = \frac{286.02}{15} = 19.07
\]

Based on the risks that have been registered and the known RPN value of each, then a critical risk can be determined. A risk is categorized as a critical risk if it has an RPN value above the critical value. The critical RPN value is determined from the average RPN value of all risks.

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Based on the RPN critical value and pareto graphs, there are 6 types of risk failures that are above 19.07 which are the RPN critical values. For these six types of risks can be seen in Table 8.

Table 8. Critical Value

| CODE | TYPE FAILURE                  | Occ | Sev | Det | Hospital | RPN   | Rank | Risk Level   |
|------|-------------------------------|-----|-----|-----|----------|-------|------|--------------|
| F1   | Coal is dusty                 | 3.5 | 3.3 | 2.75| 11.66    | 32.05 | 1    | High Risk    |
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| F4   | Self-combustion coal yard     | 2.9 | 3.1 | 2.5 | 8,994    | 22.48 | 4    | Moderate Risk|
| F10  | Hot work is not licensed      | 2.6 | 3.3 | 2.58| 8,385    | 21.63 | 5    | Moderate Risk|
| F15  | Crushers hollow body          | 2.5 | 3.8 | 2.17| 9,375    | 20.34 | 6    | Moderate Risk|

Based on the risks that have been registered and the known Risk Score value of each, then it can also be determined critical risk. Next is to analyze the critical risk comparison between risk score and RPN by using the Scatter Plot diagram. For the value of the critical category in the RPN, based on equation 1 the value is 19.07, while the value entered in the critical category for risk score refers to according to Table 8 is the one worth minimum 10 or High-Risk category.

From the scatter plot diagram shown in Figure 4, it can be seen that there is 1 failure mode that is a lot of dusty coal is a risk with a high-risk category based on matrix risk assessment at PT PJB UBJOM PACITAN. So, it can be concluded that the risk of a lot of dusty coal coming from the mine / coal yard

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in PT PJB UBJOM PACITAN is classified as the most critical risk in coal handling facility operations that need management attention. For this reason, an appropriate risk analysis is needed to determine the source or risk factors of the potential fire.

Figure 4. Scatter Plot of RPN vs. Risk Score Diagram

4. Conclusions
Focus Group Discussion again carried out to look for risk mitigation that can be done on these critical risks. And from the discussion results obtained Mitigation as follows:

4.1 Coal dust from the Mine
Risk mitigation that can be done is:
Coal from the mine before delivery is sprayed with a surfactant to prevent coal deformation. (Beamish and Smith) report other advantages of using antioxidant applications, namely less coal degradation, reducing dust problems, maintaining heating values, reducing environmental impacts and the safety of gas emissions associated with developing hotspots. [9]

- Coal transportation is prioritized using this type of ship because the location of the power plant is located in the south of Java where the sea waves are very strong and mining locations are on the island of Borneo and on the island Sumatra, resulting in long coal shipping trips when using barges. Fast delivery duration can prevent coal deformation which causes dust.
- Grab SU (Ship Unloader) has been equipped by a nozzle as a dust controller which states that with a definite pressure, efficiency is increased when the nozzle design is very small to produce smoother mist. Soft fog is more effective in dropping small dust particles from the air. [10] Likewise, modifying a smaller nozzle can produce more effective mist in controlling coal dust during the demolition process.

4.2. Coal Dust Mitigation at Coal Yard
Risk mitigation that can be done is:
- During the process of unloading coal from the Jetty to the coal field in a TT0 - TT2 conveyor belt a dust suppressor system is installed which is mixed with surfactants. So that coal is emulated with a surfactant that can bind dust and protect coal from oxygen contamination so that during the transfer process dust contamination on the conveyor becomes much less and cleaner.
- Implementation of coal use management in the coal yard area with the first in first out (FIFO) method to prevent coal deformation which can cause dust and even combustion itself. • Install a water spray / fogging jet system for coal wetting in the coal field to maintain coal temperatures at stable temperatures.
- The process of loading coal from the coal field is prioritized using a stacker and then compacted using a wheel loader by making a triangular shape from the coal core terrace to avoid the gusts of wind entering through the cavities of the coal pile.
- Install the auxiliary water fogging fan when loading using a wheel loader that can catch flying coal dust.
Based on the results of data processing and analysis using the RFMEA method of 15 types of failure equipment identified in the operation of coal handling facilities at PT. PJB UBJOM PACITAN, the type of failure that should receive management attention, is the type of failure of dusty coal, both from the origin of the mine and in the coal mine area which is the biggest risk of self-ignition/Fire. With the application of the RFMEA method, PT. PJB UBJOM PACITAN can help minimize the risk of fire that could potentially occur in power plants to improve employee safety and coal handling facilities. Thus, the power generation process can run safely.

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