Journal of Applied Science, Engineering and Technology
e-ISSN: 2722-8363 p-ISSN: 2722-8371
DOI: https://doi.org/10.47355/jaset.v5i1.76

J. ASET

Application of Failure Mode Effect Analysis (FMEA) and Ishikawa Diagram in Determining the Damage Aspects and Maintenance Plan of Screw Feeder of Steam Power Plant Company

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Received: 08.03.2025; Accepted: 03.06.2025; Published: 29.06.2025

Abstract: The screw feeder is a commonly used material transporter in various industries due to its ability to move large quantities of material and operate for extended periods. In practice, unexpected damage often occurs, requiring component replacements outside regular maintenance schedules. To improve reliability, Ishikawa diagrams are used to identify root causes of damage, while the FMEA method helps analyze failure risks and schedule preventive maintenance. This study found that the main causes of screw coal feeder damage are human error, mechanical issues, materials, and methods. Recommended actions include regular inspections for wear and proper lubrication to maintain performance. Based on reliability analysis, the screw feeder leaf has a reliability rate of 95.3% with a mean time between failure (MTBF) of 116.66 hours. The casing has a reliability rate of 94.6% and an MTBF of 142.85 hours. Implementing Ishikawa and FMEA methods at PT XYZ's coal-fired power plant (PLTU) enables more effective and planned maintenance. This approach minimizes unexpected breakdowns, improves component reliability, and ensures smoother operations.

Keywords: FMEA method; Ishikawa diagram; Material transporter; Screw coal feeder.

1. Introduction

The steam power plant (PLTU) industry generally consists of three main components: boilers, turbines, and generators. In the energy generation process, the boiler functions as a combustion chamber that burns coal to heat water, producing high-pressure steam [1-2]. This steam is then directed to the turbine blades, causing the turbine to rotate. The turbine is connected to a shaft that drives a generator to produce electrical energy. An essential part of the PLTU system is the screw coal feeder, which transports coal from the hopper to the furnace. This coal serves as the primary fuel for heating water into steam [3]. Damage to the screw coal feeder can directly disrupt the continuity of energy production, making maintenance and repair crucial. Given the frequent breakdowns of the screw coal feeder, it is vital to conduct damage analysis and regular maintenance to ensure smooth coal feeding operations and optimal functioning of all major components involved in combustion and power generation [4].

The screw feeder consists of a cylindrical casing and a rotating shaft with helical threads. It is typically used to transport bulk materials, which move gradually along the screw's threads at a controlled volume per unit. While commonly used for horizontal transport, screw feeders can also convey materials at an incline. One of the key advantages of a screw feeder is its ability to regulate the material flow rate [5].

The screw coal feeder consists of several key components: the hopper, valve, bearing, motor, gearbox, shaft, screw blade, and cover. Each of these components serves a specific function. The operating mechanism begins with refined coal stored in the hopper, which is released through a valve connected to the feeder [6]. The coal is then pushed or conveyed by the rotating screw, which is driven by a motor with power adjusted according to operational needs. The motor's power is not transmitted directly to the shaft; instead, it passes through a gearbox. The gearbox functions as a power converter, reducing the motor's load to ensure smoother operation, prevent overheating, and improve overall performance efficiency [7].

Damage or wear on components typically occurs due to operational errors as well as factors such as corrosion, cracks, and fractures. This wear can lead to production losses, machine damage, workplace accidents, increased noise, and other issues. The types of wear include: a) Friction wear (Sliding wear): Occurs when two metal or different surfaces in contact move relative to each other under load; b) Abrasive wear: Happens when metal surfaces come into contact with abrasive particles such as soil, rock, coal, sand, or other debris; c) Fretting wear: Results from repetitive back-and-forth motion between two surfaces, commonly found in press-fitted bearing joints; d) Corrosive wear: Occurs when metal surfaces are exposed to hard particles moving at certain speeds, causing surface degradation [8-9].

In combustion systems, hazardous solid materials require special handling tools due to human limitations in capacity and safety. One common solution is a conveyor, used to transport solid industrial materials. A fuel feeder is a compact version of a conveyor designed to supply fuel to the combustion chamber. According to [10], the choice of solid fuel feeders depends on material capacity, transport distance, direction (horizontal, vertical, or inclined), and the material's size, shape, and properties. The screw conveyor is ideal for moving small, lightweight solid fuels, and when adapted for feeding applications, it is called a screw conveyor feeder [11].

According to [12], technical tools should be simple, efficient, durable, safe, and easy to maintain. Material handling equipment is used to move heavy loads over short distances, either horizontally, vertically, or both [13]. These machines are grouped into: Lifting equipment: For batch unit loads (e.g., cranes, elevators), Transfer equipment: For continuous movement of bulk or unit loads (e.g., screw conveyors, belt conveyors), Surface/overhead equipment: For moving bulk or unit loads in batch or continuous form (e.g., bulldozers, excavators).

2. Materials and Methods

2.1. FMEA Methods

Failure Mode and Effect Analysis (FMEA) is a structured method used to identify, evaluate, and prevent potential failures in systems, components, or processes. It helps determine the root causes of quality issues and assess their impact on system performance. Failure modes may include design defects, conditions beyond specified limits, or functional disruptions caused by product changes. According to [14], FMEA involves four main steps: defining the system along with its functions and components, identifying possible causes of failure, analyzing their impact on the system, and developing conclusions and recommendations. The goal is to enhance system reliability by understanding the relationship between each cause of failure and its consequences, including potential secondary damage [15]. The analysis provides a comprehensive view of failure sources and supports the planning of effective maintenance strategies.

2.2. Cause Failure Mode Effect (CFME)

Cause Failure Mode Effect (CFME) is a development of the cause-and-effect diagram, used to identify the root causes of problems. The data used in creating a CFME diagram is the same as that used in a standard cause-and-effect analysis [16]. For each cause listed in the diagram, the process involves repeatedly asking "why" to trace back to the root cause—until no further answers can be provided. The results of the CFME process simplify the creation of a more detailed Cause Failure Mode Effect Analysis, as it clearly identifies failure modes, effects, and root causes [17]. The cause-and-effect diagram used in CFME is also known as a fishbone diagram due to its shape, or an Ishikawa diagram.

2.3. Calculation of the Reliability Function

Mathematically, the magnitude of machine reliability for a certain processing time (t) is obtained from one minus the probability of damage occurring during the operating time t [18]. The reliability function is according to the following equation:

$$R(t) = e -\lambda t \quad (1)$$

$$R(t) = 1\text{-}f\ (t) \quad (2)$$

Where:
R(t) = Reliability Function
Q = Overall Operating Time
F(t) = Damage Probability
F = Total Damage
λ = Damage Rate

Furthermore, if t goes to infinity, then R(t) goes to zero. F(t) is the distribution of the damage function or the unreliability function. The Unreliability function F(t) is as follows:

$$F(t) = 1\text{-}e\text{-}\lambda t \quad (3)$$

2.4. Unreliable Function

Mathematically, the magnitude of machine unreliability for a certain processing time (t) is obtained from one minus the probability of damage occurring during the t operating time [19]. The damage probability function refers to the reliability parameter as the following equation:

$$R(t) = e\ \text{-}\lambda t \quad (4)$$

$$R(t) = 1\text{-}f\ (t) \quad (5)$$

Where:
R(t) = Reliability of function
t = Overall Operating Time
F(t) = Probability of damage
F = Amount of damage
λ = Damage rate

If t goes to infinity, then R(t) goes to zero. F(t) is the distribution of the damage function or the unreliability function. The unreliability function F(t) is as follows:

$$F(t) = 1\text{-}e\text{-}\lambda t \quad (6)$$

2.5. Calculation of Average Time Between Maintenance (MTBM)

The average time between maintenance or the mean time between maintenance can be calculated based on the need for preventive maintenance (scheduled) and corrective maintenance (unscheduled) [18], according to the following equation:

$$\text{MTBM} = \frac{Total\ Effective\ Time\ of\ Machine\ Operation}{Preventive\ Maintanance\ Freq + Corrective} \quad (7)$$

$$\text{fpt} = \frac{1-(\lambda\ x\ MTBM)}{2!} \quad (8)$$

$$\text{MTBF} = \frac{1}{\lambda} \quad (9)$$

Where :
MTBM = Average time between maintenance(Mean Time Between Maintenance)
λ = Damage rate
fpt = Preventive maintenance rate
MTBF = Average time between failures (Mean Time Between Failures)

Furthermore, it can be calculated as the following equation:

$$M = MTBM\ (\lambda \text{ x } Mct) + (fpt \text{ x } Mpt) \quad (10)$$

Where:
Mct = Average time of corrective maintenance
Mpt = Average preventive maintenance time
M = Active maintenance time

2.6. Rate of Damage (Failure Rate)

The failure rate is the rate at which failure occurs at a specified time interval [20]. Damage rate (λ) is formulated as follows:

$$\lambda = \frac{f}{t} \quad (11)$$

Where:
λ = Damage Rate
F = Total Damage incurred
Q = Overall Operation Time

3. Results and Discussions

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

3.1. Component Damage Data

Data on damage to the screw coal feeder machine components in the last 6 (six) months at PT. XYZ is as table 1.

Table 2. Data on effective working hours of screw coal feeder machines

Month	Working Days	Working Hours	Total Effective Working Hours (Hours)
Jul	25	8	200
Augt	26	8	208
Sept	25	8	200
Okt	26	8	208
Nov	26	8	208
Dec	24	8	192
Total			1216

The data above was obtained through interviews with employees and the document Operating Inst Screw Coal Feeder and Spere-part catalog Screw Coal Feeder provided by maintenance.

3.2. Machine Corrective Maintenance Data

Corrective maintenance data that has been carried out on the screw coal feeder machine at PT XYZ is as shown in table 3.

Table 3. Corrective maintenance data of screw coal feeder machine

Component	Total Corrective Maintenance Time (Hours)	Number of Corrective Maintenance (Times)
Leaf Screw Feeder	16	8
Casing Screw Feeder	18	9
Total	34	17

The data above was obtained through interviews with employees and documents on the Operating Inst Screw Coal Feeder and Spare-part catalogs of the Screw Coal Feeder provided by maintenance [5]. Furthermore, based on the data above, the meantime corrective maintenance (MCT) can be calculated as follows:

$$\text{MCT} = \frac{Total\ Corrective\ Maintenance\ Time}{Lots\ of\ Corrective\ Maintenance} = \frac{34}{17} = 2 \text{ Hours}$$

3.3. Preventive Maintenance Data

Furthermore, the preventive maintenance data for the screw coal feeder machine components is as shown in table 4.

Table 4. Data on Preventive Maintenance of PT XYZ's screw coal feeder machine components

Component	total preventive maintenance (hours)	Number of Preventive maintenance (Times)
Weekly maintenance	8	1

The data in table 4 above were taken for 6 months which were included in the calculation range and were sampled based on damage data on 2 (two) types of components, namely screw feeder leaves and screw feeder casing.

3.4. Failure Mode and Effect Analysis (FMEA)

FMEA is a method that aims to evaluate system design by considering various types of damage from the system by considering various types of damage from the system that occurs from components, analyzing the effects of component damage from critical systems can be assessed and the actions needed to improve design and eliminate or reduce the probability of critical damage methods can be seen in table 5.

Table 5. FMEA screw coal feeder components

Component	Function	Functional Failure	Failure mode	Failure Effect
Leaf Srew Feeder	To push and transport coal to the combustion chamber	there was a failure of the screw leaf and the release of the welded joint on the shaft	The rotation of the motor becomes heavy, it gets hot easily and the motor power decreases	some of the coal is not transported to the combustion chamber because the motor rotation is reduced and the screw leaves are broken so that combustion is not optimal
Casing Screw Feeder	to keep coal on the track	the occurrence of failure or tear in the case	Coal out of the track so that the bearing wears out faster due to pressure on the shaft	Coal is not optimally transported to the combustion chamber because it goes off the track

Failure mode analysis and effect analysis is carried out to see the various types of damage to the system that occur from components, analyze the effects on system constraints by tracing the effects of component damage from critical systems can be assessed and the actions needed to repair critical component damage. In the corrective action taken, the components were damaged which resulted in the engine not working optimally. From the results of FMEA processing, damaged components must be replaced immediately. In this replacement, it must be done as soon as possible so that the damaged component does not damage other components. The actions that must be taken on these two components include Screw Feeder Leaves and Screw Feeder Casing, which must be checked for wear and lubrication so that these components are always good in their use and the need for planned maintenance and regular replacement [21].

3.5. Damage Rate

Damage rate (λ) of the Screw Coal Feeder machine components and the mathematical equations used to find the damage rate using the formula are as follows:

$$\lambda = \frac{Lots\ of\ Corrective\ Maintenance}{Total\ Effective\ Hours\ of\ Machine\ Operation}$$

Breakage rate for Coal feeder screw leaf components:

$$\lambda = \frac{8}{1216} = 0{,}006 \text{ kerusakan/jam}$$

Damage rate for screw feeder casing components

$$\lambda = \frac{9}{1216} = 0{,}007 \text{ kerusakan/jam}$$

Based on the calculation above, the Leaf Screw Feeder component will suffer damage of 0.006 damage/hour and Casing Screw Feeder will suffer damage of 0.007 damage/hour.

3.6. MTBF Machine Components

Mean Time Between Failure (the average time between failures) can be calculated as follows:

$$\text{MTBF} = \frac{1}{\lambda}$$

where, the MTBF for the screw feeder leaf component is:

$$\text{MTBF} = \frac{1}{0{,}006} = 116{,}66 \text{ jam} = 6{,}94 \text{ x } 3 \text{ minggu} = 21 \text{ hari}$$

and MTBF for screw feeder casing components

$$\text{MTBF} = \frac{1}{0{,}007} = 142{,}85 \text{ jam} = 5{,}95 \text{ x } 3 \text{ minggu} = 18 \text{ hari}$$

Based on the calculation above, the Srew Leaf Feeder component will be damaged after 21 days of operation, while the Casing Screw Feeder will be damaged after 18 days of operation.

3.7. Unreliability function

The unreliability function can be defined as the probability of a component failure occurring within a time span (t), and can be calculated as follows:

F(t)= 1-e-λt

Where the unreliability function for the screw feeder leaf component for t = 8 hours is:

F(8) = 1-e-0.006x8 = 0.047 = 4.7 %

Furthermore, the unreliability function for the Casing Screw Feeder component for t = 8 hours is:

F(8) = 1-e-0.007x8 = 0.054 = 5.4 %

From the calculation above, the probability of damage occurring to the Leaf Screw Feeder component is 4.7% in percentage, while the probability of damage occurring to the Casing Screw Feeder component is 5.4% in percentage.

3.8. Reliability Function

The reliability function can be interpreted how often the component is damaged at time (t) and the mathematical equation is as follows:

R(t) = e-λt

Where is the reliability function for the Leaf Screw Feeder component for t = 8 is:

R(8) = e-0.006x8 = 0.953 = 95.3 %

Furthermore, the reliability function for the Casing Screw Feeder component for t = 8 is:

R(8) = e-0.007x8 = 0.946 = 94.6 %

Based on the calculation above, for the screw feeder leaf component the frequency of damage is 95.3% which is classified as often damaged, then for the screw feeder casing component it is 94.6%. The reliability value of the screw feeder casing components is slightly lower than the screw feeder leaves. In general, the level of frequency of damage to the two components can be classified as high or often experience damage.

3.9. Average Time Between Maintenance

The mean time between maintenance (MBTM) includes preventive maintenance (scheduled) and corrective maintenance (unscheduled). The calculation of the machine's MBTM is as follows:

$$\text{MTBM} = \frac{Total\ Effective\ Time\ of\ Machine\ Operation}{Preventive\ Maintanance\ Freq + Corrective}$$

MTBM for Leaf Screw Feeder components:

$$\text{MTBM} = \frac{1216}{28+8} = \frac{1216}{36} = 33{,}8\ \text{jam} = 1{,}4\ \text{hari}$$

Furthermore, the MTBM for the Casing Screw Feeder component is:

$$\text{MTBM} = \frac{1216}{28+9} = \frac{1216}{37} = 32{,}8\ \text{jam} = 1{,}3\ \text{hari}$$

Mean Time Between Failure (average time) From the calculation results above, the Leaf Screw Feeder component must be maintained every 33.3 hours or 1.4 days once a day, and for the Casing Screw Feeder component, maintenance must be carried out every 32.8 hours. or 1.3 days 1 time.

3.10. Fpt Damage to Machine Components

Fpt or active maintenance frequency can be calculated as follows:

$$\text{Fpt} = \frac{1 - (MTBM\ x\ \lambda)}{MTBM}$$

Fpt for Leaf Screw Feeder components

$$\text{Fpt} = \frac{1 - (33{,}8\ x 0{,}006)}{33{,}8} = 0{,}0235$$

Furthermore, the Fpt for the Casing Screw Feeder component is:

$$\text{Fpt} = \frac{1 - (32{,}8\ x 0{,}007)}{32{,}8} = 0{,}0234$$

Based on the calculation results for the Screw Feeder Leaf component, 0.0235 maintenance/hour preventive maintenance must be carried out, while for the Casing Screw Feeder component, 0.0234 maintenance/hour preventive maintenance must be carried out.

3.11. Mean Maintenance Time (Mct)

Mean Maintenance Time (Mct) is the time required for corrective maintenance or component replacement per 1 component, the equation used is as follows:

$$\text{Mct} = \frac{Total\ Corrective\ Maintenance\ Time}{Lots\ of\ Corrective\ Maintenance}$$

For Leaf Screw Feeder components

$$\text{Mct} = \frac{16}{8} = 2 \text{ jam}$$

For Screw Feeder Casing components

$$\text{Mct} = \frac{18}{9} = 2 \text{ jam}$$

From the calculation above, to replace 1 component of the Leaf Screw Feeder it takes an average of 2 hours, while to replace 1 component of the Casing Screw Feeder it takes an average of 2 hours.

3.12. Average Active Maintenance Time (M)

The average time of active maintenance (M) is the time needed to carry out preventive and corrective maintenance.

$$\text{M} = \frac{(\lambda\ x\ Mct) + (Fpt\ x\ Mpt)}{\lambda + Fpt}$$

Average time of active maintenance for Leaf Screw Feeder components

$$\text{M} = \frac{(0{,}006\ x\ 2) + (0{,}0235\ x\ 8)}{0{,}006 + 0{,}0235} = 6{,}77 \text{ jam}$$

The average active maintenance time for the Casing Screw Feeder component

$$\text{M} = \frac{(0{,}007\ x\ 2) + (0{,}0234\ x\ 8)}{0{,}007 + 0{,}0234} = 6{,}61 \text{ jam}$$

From the results of the calculation above, it takes 6.77 hours to carry out preventive and corrective maintenance (routine maintenance + replacement) of the Screw Feeder Casing component, while to carry out preventive and corrective maintenance (routine maintenance + replacement) of the Casing Screw Feeder component it takes 6.61 hours. Maintainability are factors that show a characteristic of system engineering and have characteristics to facilitate maintenance, accuracy, safety and economic factors in carrying out functions [4-6]. The maintainability analysis includes the following functions:

Leaf Screw Feeder Components, the average corrective maintenance time (Mct) = 2 hours, the average preventive maintenance time (Mpt) = 8 hours. The average time between maintenance (including corrective and preventive) mean time between maintenance (MTBM) = 33.8 hours. So the Screw Coal Feeder machine must be maintained for damage to the Screw Feeder Leaf components every 33.8 hours. Scheduled individual maintenance frequency / frequency preventive time (Fpt) = 0.0235 hours, the mean maintenance time (M) = 6.77 hours. Casing Screw Feeder Components, the average corrective maintenance time (Mct) = 2 hours, the average preventive maintenance time (Mpt) = 8 hours. The average time between maintenance (including corrective and preventive) mean time between maintenance (MTBM) = 32.8 hours. So, the Screw Coal Feeder machine must be maintained for damage to the Casing Screw Feeder components every 32.8 hours. Scheduled individual maintenance frequency / frequency preventive time (Fpt) = 0.0234 hours, the mean maintenance time (M) = 6.61 hours.

3.13. Ishikawa Diagrams (Cause and Effect diagrams)

To analyze the causes of damage in the Leaf Screw Feeder and Casing Screw Feeder components, a fishbone diagram (cause and effect diagram) was used. This tool helps visualize and categorize potential factors contributing to the problem, which are grouped into four main categories: material, method, human, and machine. The material-related causes include the use of substandard materials, often resulting from procurement that does not meet the specified requirements. These poor-quality materials contribute to early wear and corrosion. From the method perspective, the root causes involve non-compliance with standard operating procedures and the absence of a structured preventive maintenance plan. These lapses increase the likelihood of unexpected breakdowns. Human factors also play a significant role, particularly in cases where maintenance is not performed according to schedule, there is a lack of coordination from supervisors, and mechanical staff show inadequate discipline or attention to detail. Lastly, machine-related causes include physical damage due to collisions and friction between the casing and screw leaf, insufficient lubrication in the bearings and gearbox, and general wear caused by aging equipment. These mechanical issues accelerate deterioration and reduce component reliability. In summary, the damage to both the Leaf Screw Feeder and Casing Screw Feeder is the result of interconnected factors, highlighting the need for improved material selection, strict adherence to procedures, better maintenance planning, and enhanced human resource management.

4. Conclusions

Damage that occurs in the Screw Coal Feeder machine, especially the components of the Screw Feeder Leaf and the Casing Screw Feeder are generally caused by several factors, such as: humans, machines, foreign materials, and the method of maintaining the machine. Based on the FMEA method, the effects of the failure of the screw coal feeder machine are: damage/tears in the screw leaf and loose welding joints on the shaft, the result is that the coal being transported is not optimal due to reduced motor rotation and damage to the casing which can result in rock transport paths embers become inconsistent. The low reliability of the Leaf Screw Feeder component is 95.3% and the Casing Screw Feeder component is 94.6%. The MTBF of the Screw Feeder leaf component is 116.66 hours and the Casing Screw Feeder component is 142.85 hours.

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