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Failure Mode Analysis of Injection Molding Machines Using FMEA to Improve Production Reliability

Bayu Wahyudi[1], Asrul Fole[2*], Muhamad Alfi Syahrin[3], Nurul Binti Gafar[4], Yasmin[5]

[135]Department of Industrial Engineering, Universitas Muhammadiah Palembang, Indonesia

[24]Department of Industrial Engineering, Universitas Muslim Indonesia, Indonesia

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*Corresponding Author

Asrul Fole

E-mail: asrulfole@umi.ac.id

ABSTRACT

Production reliability plays an important role in maintaining operational efficiency and product quality in manufacturing industries, particularly in injection molding machine systems. However, machine failures often cause downtime, defective products, and increased maintenance costs. This study aims to analyze failure modes in injection molding machines using the Failure Mode and Effects Analysis (FMEA) method to improve production reliability at the South Sumatra Palm Oil Processing Industry. The research employed a quantitative descriptive-analytical approach, using observations, interviews, documentation, and maintenance records collected during August 2025. The analysis focused on critical machine components, including the mold, heater band, cutting system, hydraulic pump, and thermocouple. The results showed that the mold failure coded M1 had the highest Risk Priority Number (RPN) of 140, followed by the cutting failure C1 with 120 and the mold closing failure M2 with 108. Pareto analysis indicated that approximately 60% of operational disruptions were caused by four dominant failures. The proposed preventive maintenance and inspection strategies are expected to significantly reduce operational disruptions and improve production reliability.

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INTRODUCTION

In modern manufacturing systems, production reliability has become a crucial factor in maintaining operational efficiency, minimizing downtime, and ensuring consistent product quality [1]. Industrial machinery, particularly injection molding machines, plays an important role in supporting continuous production processes in manufacturing industries [2]. However, machine failures frequently occur because of component degradation, unstable operating conditions, inadequate maintenance activities, and operator errors, resulting in productivity loss and increased operational costs [3]. Several studies have shown that unexpected machine breakdowns significantly affect manufacturing performance and reduce product quality consistency, emphasizing the importance of systematic failure analysis to improve production reliability and maintenance effectiveness in industrial systems [1], [4].

Specifically, failures in injection molding machines often lead to production delays, defective products, and interruptions in manufacturing activities due to unstable temperature conditions, hydraulic pressure inconsistencies, and mechanical malfunctions [5]. In manufacturing industries, repeated machine failures are strongly associated with ineffective maintenance planning and insufficient risk-based analysis approaches [6], [7]. Previous studies reported that breakdown losses in molding systems could reach critical levels, with Risk Priority Number (RPN) values exceeding 100 in high-risk machine components [8], [9]. To overcome these issues, the Failure Mode and Effects Analysis (FMEA) method is widely applied as a structured analytical approach to identify potential failure modes, evaluate their impacts, and prioritize corrective maintenance actions effectively [10].

This study was conducted South Sumatra Palm Oil Processing Industry, a palm oil processing company where injection molding machines are utilized in the packaging process. The molding machine unit frequently experiences operational disruptions that negatively affect production continuity and machine performance [11], [12]. Data collected during August 2025 identified several critical component failures, including mold, cutting molding, and heater band failures, with RPN values of 140, 120, and 112, respectively. These failures contribute significantly to production downtime, increased maintenance costs, and product quality inconsistencies. Similar reliability issues in manufacturing systems were also reported in previous studies emphasizing the importance of reliability-centered maintenance strategies in industrial operations [13], [14].

Previous studies have demonstrated that FMEA is an effective method for identifying, evaluating, and prioritizing failures in manufacturing systems [10]. Data-driven FMEA approaches have been developed to improve maintenance planning and support decision-making processes using historical operational data and machine performance indicators [3], [9]. Furthermore, hybrid FMEA models integrating fuzzy logic, probabilistic analysis, and risk-based maintenance approaches have been proposed to overcome the limitations of traditional RPN calculations [15]. Research on molding systems has also confirmed that FMEA significantly improves machine reliability, minimizes production defects, and enhances operational efficiency in the plastic manufacturing industry through systematic risk evaluation and maintenance planning [16], [17].

Despite its extensive implementation in manufacturing industries, many previous studies focus primarily on general failure identification, without providing detailed component-level analysis and practical maintenance strategies tailored to specific industrial environments [18], [19]. Moreover, studies on injection molding machines in the palm oil processing industry remain relatively limited. Recent research highlighted the importance of integrating real operational data, preventive maintenance strategies, and advanced reliability approaches to improve failure prediction and maintenance prioritization [20]. Therefore, this study proposes a more comprehensive FMEA-based analysis by incorporating severity, occurrence, and detection assessments to yield more accurate risk prioritization and actionable maintenance recommendations, thereby improving production reliability [21].

The objective of this study is to analyze failure modes in injection molding machines using the FMEA method to improve production reliability and maintenance performance. This research aims to identify critical machine components, evaluate their risk levels, and propose effective corrective and preventive maintenance strategies based on RPN values [17]. The findings are expected to reduce machine downtime, improve operational efficiency, and maintain product quality consistency in manufacturing activities. In addition, this study contributes to the development of reliability engineering practices and maintenance decision-making systems in manufacturing industries, particularly through the application of systematic risk analysis and maintenance optimization approaches.

RESEARCH METHODS

This study employs a quantitative descriptive-analytical approach to analyze failure modes in injection molding machines using the Failure Mode and Effects Analysis (FMEA) method. Conducted at South Sumatra Palm Oil Processing Industry from August 1–30, 2025, the research focuses on critical components such as mold, heater band, and cutting system. Primary data were collected through observation, interviews, and documentation, while secondary data came from maintenance records.

The FMEA method was applied to evaluate potential failures by identifying their causes, effects, and risk levels. The analysis considers three main parameters, namely severity, occurrence, and detection, which are assessed using a rating scale from 1 to 10 based on expert judgment and operational data. The steps for implementing the FMEA method are as follows:

1. Identify failure modes in each component of the injection molding machine based on field observations and historical data.
2. Determine the causes and effects of each failure mode on production performance and product quality.
3. Assign Severity (S), Occurrence (O), and Detection (D) values using standardized rating criteria derived from expert evaluation.
4. Calculate the Risk Priority Number (RPN) to determine the level of risk for each failure mode.

$$RPN = S \times O \times D \quad (1)$$

5. Classify risk levels based on RPN values into categories: low, medium, high, and critical.
6. Prioritize failure modes according to the highest RPN values to identify critical components requiring immediate attention.
7. Apply Pareto analysis to determine dominant failure contributors using cumulative percentage evaluation.
8. Develop improvement recommendations based on the analysis results, focusing on preventive maintenance, corrective actions, and operational optimization.

Additionally, the percentage contribution of each failure mode to the total risk is calculated using the following equation:

$$\text{Percentage Contribution} = \frac{RPN_i}{\sum RPN} \times 100\% \quad (2)$$

where:
RPN_i = Risk Priority Number of each failure mode
$\sum RPN$ = Total Risk Priority Number of all failure modes

The overall methodology provides a systematic framework for identifying critical failures, prioritizing risks, and improving machine reliability. By integrating FMEA with Pareto analysis, this study enables more effective decision-making in maintenance management and supports continuous improvement in manufacturing performance..

RESULTS AND DISCUSSION

This section presents the results of the Failure Mode and Effects Analysis (FMEA) conducted on injection molding machines, including risk evaluation, Pareto analysis, and recommendations for improving production reliability.

1. Identification of Failure Modes

Based on field observations and interviews with technicians and machine operators, several failure modes were identified in the injection molding machine components. These failures can disrupt production processes, reduce product quality, and increase machine downtime.

Table 1. Identification of Failure Modes in Injection Molding Machine Components

No	Component	Type of Failure	Code
1	Heater Band	No heat generated or uneven heating	HB1
2		Burnt or scorched surface	HB2
2	Mold	Cavity surface scratched, corroded, or worn out	M1
4		Mold difficult to open or not perfectly closed	M2
5	Control Panel	The monitor screen does not turn on	CP1
6		Control buttons do not respond	CP2
7	Hydraulic	Noisy sound during pump operation	HP1
8	Pump	Oil leakage around the pump	HP2
9	Thermocouple	Unstable or fluctuating temperature readings	T1

No	Component	Type of Failure	Code
10		Temperature not displayed on the control panel	T2
11	Cutting	Uneven cutting results	C1
12		Dull molding blade	C2
13	Cooling Line	Uneven product cooling	CL1
14		Blocked cooling water flow	CL2

The results presented in Table 1 indicate that most failures occur due to component wear, unstable operating conditions, and insufficient maintenance practices. Critical failures in the mold, heater band, and cutting components directly affect product quality and production continuity. Meanwhile, failures in the hydraulic pump and cooling line contribute to unstable machine performance during operation. These findings demonstrate the importance of systematic failure identification in supporting risk evaluation and maintenance improvements using the FMEA method

2. **Analysis of Severity, Occurrence, and Detection**

The identified failure modes were evaluated using the FMEA parameters: Severity (S), Occurrence (O), and Detection (D). The assessment was conducted using expert judgment by technicians and operators, based on operational conditions, maintenance records, and the impact of failures on production reliability.

Table 2. Severity, Occurrence, and Detection Assessment of Failure Modes

Code	Type of Failure	Severity (S)	Occurrence (O)	Detection (D)
HB1	No heat generated or uneven heating	8	4	3
HB2	Burnt or scorched surface	7	3	3
M1	Cavity surface scratched, corroded, or worn out	10	7	2
M2	Mold difficult to open or not perfectly closed	9	6	2
CP1	The monitor screen does not turn on	7	3	3
CP2	Control buttons do not respond	6	3	3
HP1	Noisy sound during pump operation	8	5	2
HP2	Oil leakage around the pump	7	4	2
T1	Unstable or fluctuating temperature readings	6	4	3
T2	Temperature not displayed on the control panel	7	3	3
C1	Uneven cutting results	8	5	3
C2	Dull molding blade	7	4	3
CL1	Uneven product cooling	7	4	2
CL2	Blocked cooling water flow	6	3	2

The assessment results in Table 2 indicate that failure modes related to mold components, particularly M1 and M2, have the highest Severity and Occurrence scores due to their significant impact on production continuity and product quality. Meanwhile, failures such as CL2 and CP2 show relatively lower risk levels because they occur less frequently and can be detected earlier. Detection values ranging from 2 to 3 indicate that most failures are moderately difficult to identify before they cause operational disruptions. These findings provide the basis for determining the Risk Priority Number (RPN) in the next stage of analysis.

3. **Risk Priority Number (RPN) Calculation**

The Risk Priority Number (RPN) calculation was performed to determine the priority level of each identified failure mode in the injection molding machine system. The RPN values were obtained by multiplying the Severity (S), Occurrence (O), and Detection (D) scores to identify the most critical failures affecting production reliability.

Table 3. Risk Priority Number (RPN) Calculation Results

No	Code	Severity (S)	Occurrence (O)	Detection (D)	RPN
1	HB1	8	4	3	96
2	HB2	7	3	3	63
3	M1	10	7	2	140

No	Code	Severity (S)	Occurrence (O)	Detection (D)	RPN
4	M2	9	6	2	108
5	CP1	7	3	3	63
6	CP2	6	3	3	54
7	HP1	8	5	2	80
8	HP2	7	4	2	56
9	T1	6	4	3	72
10	T2	7	3	3	63
11	C1	8	5	3	120
12	C2	7	4	3	84
13	CL1	7	4	2	56
14	CL2	6	3	2	36

The results presented in Table 3 indicate that the failure mode coded M1, namely “cavity surface scratched, corroded, or worn out,” has the highest RPN value of 140, making it the most critical failure affecting machine reliability and production continuity. This value is influenced by the highest Severity score of 10 and Occurrence score of 7, indicating severe impacts and frequent occurrences during operation. The second-highest RPN value is identified in C1 (uneven cutting results) with a score of 120, followed by M2 with an RPN value of 108 and HB1 with 96. In contrast, CL2 shows the lowest RPN value of 36, indicating a relatively low operational risk. Failure modes with RPN values above 100 are classified as critical and require immediate corrective actions, preventive maintenance scheduling, and component monitoring to reduce downtime and improve production reliability within the injection molding system.

4. Pareto Analysis of Critical Failures

A Pareto analysis was conducted to identify the dominant failure modes contributing to production disruptions in the injection molding machine system. The analysis was based on the Risk Priority Number (RPN) values obtained from the FMEA evaluation of each machine component failure.

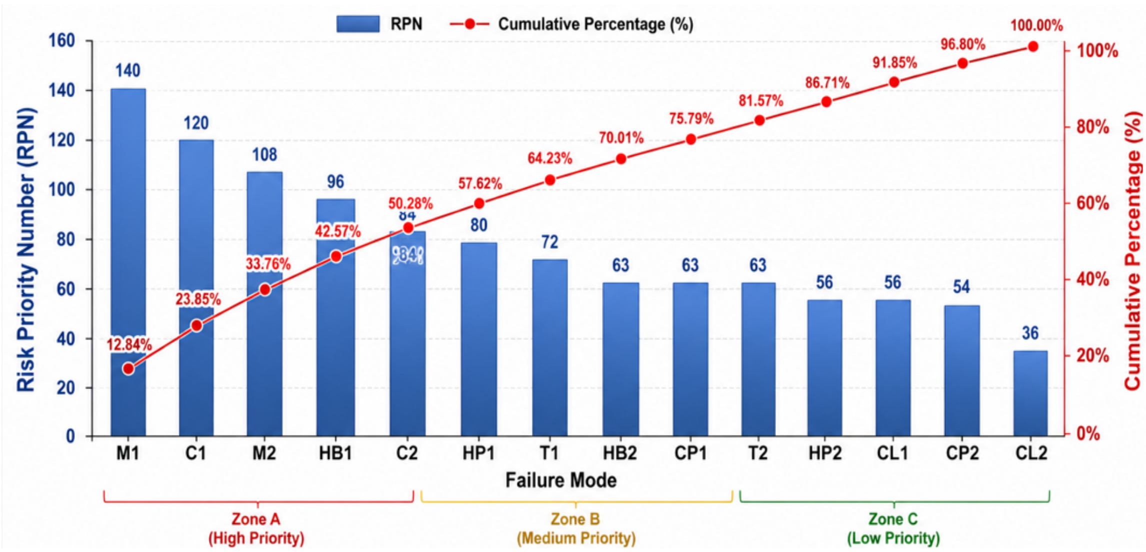

Fig.1. Pareto Diagram of Critical Failures

The Pareto diagram in the figure 1 indicates that the failure modes coded as M1, C1, M2, and HB1 account for the majority of operational problems in the injection molding system. The highest contribution is from M1, with an RPN of 140, followed by C1 at 120 and M2 at 108. These three critical failures account for approximately 48% of the cumulative total risk. When combined with HB1, which has an RPN value of 96, the cumulative contribution increases to nearly 60% of total operational disruptions. According to the Pareto principle, a limited number of critical failures are responsible for most production problems. Therefore, maintenance improvement efforts should prioritize mold, cutting, and heater band components through preventive maintenance, routine inspections, and scheduled component replacements to minimize downtime and improve production reliability.

5. Improvement Recommendations

Improvement recommendations were developed based on the critical failure modes identified through the FMEA and Pareto analyses. The proposed actions focus on reducing high-risk failures, improving machine reliability, minimizing production downtime, and enhancing maintenance effectiveness within the injection molding machine system.

Table 4. Improvement Recommendations for Critical Failures

Failure Code	Cause of Failure	Effect on Production	Mitigation Action	Estimated Completion Time
M1	Continuous friction and lack of maintenance	Defective products and production stoppage	Routine mold inspection, polishing, and scheduled replacement	14 days
C1	Dull cutting blade and unstable alignment	Inconsistent product dimensions	Blade replacement and cutting system calibration	7 days
M2	Mechanical wear and improper lubrication	Delayed production cycle	Lubrication scheduling and mold alignment adjustment	10 days
HB1	Heater band deterioration and unstable electrical flow	Uneven product formation	Periodic heater band inspection and electrical maintenance	5 days
C2	Dull molding blade and inaccurate trimming process	Irregular product edges and reduced dimensional accuracy, leading to increased rework and product rejection	Replace worn molding blades, perform routine sharpening, implement preventive maintenance, and conduct periodic equipment calibration	7 days

Based on Table 4, the proposed improvement recommendations focus on mitigating the most critical failure modes identified through the FMEA analysis. Failure code M1 requires the longest implementation period, namely 14 days, because mold inspection, polishing, and scheduled replacement involve detailed maintenance activities that directly affect product quality and production continuity. Failure codes C1 and C2 each require 7 days to complete corrective actions, including blade replacement, equipment calibration, and periodic sharpening to ensure dimensional accuracy and consistent product quality. Failure code M2 can be addressed within 10 days through lubrication scheduling and mold alignment adjustments to reduce delays caused by mechanical wear. Meanwhile, HB1 requires only 5 days for preventive electrical maintenance and heater band replacement. The implementation of these corrective actions is expected to reduce equipment failures, minimize production downtime, improve product consistency, enhance machine reliability, and strengthen preventive maintenance practices. Additionally, regular inspections and operator involvement are essential to improve early fault detection and prevent recurring failures during manufacturing operations.

6. Implications of FMEA Implementation on Production Reliability Improvement

The implementation of the FMEA method in injection molding machines successfully identified critical failure modes affecting production reliability at South Sumatra Palm Oil Processing Industry. The analysis revealed that the mold component failure, coded M1, had the highest RPN value of 140, followed by the cutting failure, C1, with 120, and the mold closing failure, M2, with 108. These results indicate that mold-related failures contribute significantly to production downtime and defective products. Similar findings were reported in previous studies, indicating that FMEA is effective for prioritizing maintenance actions and improving manufacturing reliability through systematic risk evaluation and maintenance planning in industrial systems [16], [17], [21].

The Pareto analysis results indicate that approximately 60% of operational disruptions stem from four dominant failure modes: M1, C1, M2, and HB1. This finding aligns with the Pareto principle, in which a limited number of failures account for the majority of production problems and operational inefficiencies [12], [22]. Previous studies conducted by [2]. confirmed that molding machine failures are commonly caused by component wear, unstable temperature conditions, and insufficient maintenance procedures [23]. Similarly, reliability studies in manufacturing systems have emphasized that inadequate preventive maintenance significantly increases machine breakdown frequency, operational downtime, and production interruptions[20].

The proposed improvement recommendations emphasize the implementation of preventive maintenance, periodic inspections, machine component calibration, and operator monitoring. The implementation of scheduled mold maintenance and heater band inspections is expected to reduce unexpected breakdowns and stabilize production performance. Based on the analysis, corrective actions for mold and cutting components could reduce operational disruptions by more than 40%. Similar findings were reported by Bokrantz et al., who stated that data-driven maintenance strategies, integrated with FMEA, improve failure detection capabilities and support effective maintenance decision-making in industrial systems [16], [17]. Other studies have also highlighted that implementing preventive maintenance contributes significantly to increased machine availability, improved operational efficiency, and reduced production losses in manufacturing systems [24], [25].

Furthermore, applying FMEA provides practical benefits for manufacturing management by improving machine reliability and supporting continuous production. The integration of Severity, Occurrence, and Detection assessments enables companies to identify high-risk failures more accurately and allocate maintenance resources more efficiently. In addition, operator training programs and routine monitoring activities help improve early failure detection capabilities and minimize recurring failures. These findings strengthen previous studies indicating that FMEA not only minimizes production risk but also enhances product quality, operational stability, and overall manufacturing performance in industrial environments through structured maintenance planning and reliability-centered decision-making approaches.

CONCLUSION

This study successfully applied the Failure Mode and Effects Analysis (FMEA) method to identify, evaluate, and prioritize critical failures in injection molding machines at South Sumatra Palm Oil Processing Industry. The results indicate that the mold component failure coded M1, namely "cavity surface scratched, corroded, or worn out," has the highest Risk Priority Number (RPN) value of 140, followed by uneven cutting results (C1) with an RPN value of 120 and mold closing failure (M2) with 108. These failures significantly affect production continuity, machine reliability, and product quality. The Pareto analysis further revealed that approximately 60% of operational disruptions are caused by four dominant failures, namely M1, C1, M2, and HB1, indicating that a limited number of critical components contribute to most production problems. The implementation of corrective actions such as preventive maintenance scheduling, mold inspection, cutting blade replacement, and heater band calibration is expected to reduce operational disruptions by more than 40% and improve machine performance. Therefore, the company is recommended to strengthen routine maintenance systems, improve operator training programs, and conduct periodic monitoring of critical machine components to minimize unexpected downtime. For future research, it is recommended to integrate FMEA with other decision-support methods such as AHP, TOPSIS, or predictive maintenance approaches to obtain more comprehensive and accurate reliability analysis results in manufacturing systems.

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