

# Maintenance System Improvements to Increase Reliability of Continuous Frying Machine Using FMECA and RCM

Indro Prakoso<sup>a,\*</sup>, Ari Andriyas Puji<sup>b</sup>, Nur Fitriyah Mufarrihah<sup>a</sup>, Amanda Sofiana<sup>a</sup> and Ali Alhamidi<sup>a</sup>

<sup>a)</sup>Department of Industrial Engineering, Faculty of Engineering, Universitas Jenderal Soedirman, Purwokerto, Indonesia

<sup>b)</sup>Department of Mechanical Engineering, Universitas Riau, Pekanbaru, Indonesia

\*Corresponding author: prakosoindro@unsoed.ac.id

## Paper History

Received: 30-June-2026

Received in revised form: 14-July-2026

Accepted: 30-July-2026

## ABSTRACT

The optimization of maintenance remains still a challenge in food manufacturing since preventive maintenance is often scheduled at fixed intervals without considering the criticality of components and the real characteristics of failures. Failure Modes, Effects and Criticality Analysis (FMECA) and Reliability-Centered Maintenance (RCM) are two popular tools for planning maintenance. However, only a limited number of studies have combined the two methods to determine the reliability-based maintenance intervals of continuous frying machines based on real industrial failure data. This study propose is to integrate maintenance framework with combining the FMECA and RCM to identify critical components, select appropriate maintenance tasks and define maintenance intervals according to the components' reliability. The framework was implemented on a continuous frying machine at PT. XYZ and found the wire mesh to be the most critical component. The suggested maintenance intervals were 35 days for the drum filter, 150 days for the circulation pump, 67 days for the pedal, and 14 days for the wire mesh. The Time-Directed Maintenance (TMD) task recommended a preventive replacement interval of 180 days for the circulation pump. The proposed framework provides a systematic approach of maintenance decision making in food manufacturing and demonstrates its practical effectiveness by improving the machine reliability from 1.6% to 13.3% and machine availability from 55.1% to 99.8%.

**KEYWORDS:** Availability, FMECA, RCM, Reliability, Total Minimum Downtime.

## NOMENCLATURE

RCM Reliability Centered Maintenance

FMECA Failure Mode, Effects, and Criticality Analysis

FMEA Failure Mode and Effects Analysis

CA Critical Analysis

RPN Risk Priority Number

LTA Logic Tree Analysis

MTTF Mean Time to Failure

MTTR Mean Time to Repair

TTF Time To Failure

TTR Time To Repair

MLE Maximum Likelihood Estimator

TMD Total Minimum Downtime

NoF Number of Failure

NoM Number of Maintenance

$R(t)$  Reliability value at time  $t$

$F(t)$  Cumulative probability of failure at time  $t$

$T_p$  Preventive replacement time

$T_f$  Repair time upon failure

$M(t)$  Minimum downtime calculation at interval  $t$

$D(t)$  Downtime value at interval  $t$

## 1. INTRODUCTION

The manufacturing industry has undergone major changes due to global growth and competition. Therefore, all companies need to optimize their production activities so that they run effectively and efficiently. To optimize production activities, it is necessary to increase the productivity of the production system. The degree of reliability of a company's production machines is a measure or indicator of increasing productivity levels [1]. The level of machine reliability is the ability of the machine to function properly within the expected time [2]. Therefore, machine reliability analysis is required to determine the possibility that the machine or component can perform well to achieve efficiency, productivity and performance in the production process. One way to maintain the pace of production activities so that they can continue to run smoothly is to carry out maintenance activities. One company that has performed maintenance is PT. XYZ.

PT. XYZ is a manufacturing industry operating in the food and beverage sector. In its production process, this company has used various machines including a continuous frying. Continuous frying is a machine for continuously frying products, which consists of two stages. In practice, the company performed maintenance at regular intervals over

daily, monthly and annual periods, but these were not carried out in accordance with maintenance time intervals based on the characteristics of the damage. Based on the monitoring of daily preventive maintenance activities, the number of NoF (Number of Failure) is higher than NoM (Number of Maintenance). This suggests that the preventive maintenance measures carried out are still not optimal, as damage still occurs frequently, disrupting the production process and the resulting performance is not optimal. Furthermore, a high NoF results in machine maintenance schedules sometimes having to be postponed from the specified schedule, which may result in a reduction in machine performance due to delays in maintenance activities [3]. Therefore, a strategy to optimize existing maintenance activities is required.

To optimize maintenance activities based on the level of reliability, you can use the RCM (Reliability Centered Maintenance) method. RCM is a method of developing maintenance schedules that takes into account reliability and ensures operational performance [4]. Based Supriyanto et al. [4] have shown that the use of RCM to determine appropriate maintenance tasks and prevent possible system damage. System damage analysis can be carried out using the Failure Mode Effect and Critical Analysis (FMECA) method [4]. FMECA is a technique for analyzing potential failure modes of a system using a classification based on the severity or impact assessment of a failure [5].

The aim of this research is to improve the maintenance system of the continuous fryer machine by suggesting necessary maintenance actions for all components. All components are analyzed using the FMECA method to rank the criticality of the components and develop corrective actions if a failure occurs. Meanwhile, RCM is used to develop maintenance strategies and maintenance time intervals based on the level of machine reliability. Although Failure Modes, Effects, and Criticality Analysis (FMECA) and Reliability-Centered Maintenance (RCM) have been extensively utilized in maintenance research, the majority of studies have focused on general manufacturing equipment or isolated maintenance decision models [6]. Limited research has addressed the combination of component criticality analysis with reliability-based maintenance interval determination specifically for continuous frying machines in the food manufacturing sector [7].

Moreover, studies that explicitly combine FMECA, RCM, and maintenance interval evaluation based on actual failure characteristics in continuous frying operations are rare [6]. This illustrates a significant research gap in developing a systematic maintenance framework that recognizes critical components, assigns appropriate maintenance tasks, and determines maintenance intervals based on the operational characteristics of these machines. To fill this gap, this study proposes an integrated maintenance framework that combines FMECA and Reliability-Centered Maintenance (RCM) to identify the critical components, to determine the appropriate maintenance tasks and to establish the reliability-based maintenance intervals for continuous frying machines. The novelty of this study is the combination of component criticality analysis with the determination of the reliability-based maintenance interval using real failure data. This framework contributes by providing a systematic approach to improve machine reliability and availability in the food manufacturing.

## 2. METHODS

This research aims to provide suggestions for the maintenance of all machine components based on a given level of reliability. The data used primary and secondary data. The primary data was obtained directly by the author through interviews and brainstorming with technicians or heads of maintenance departments. The primary data of this research was machine component data and data on the causes and effects of damage to the machine. Secondary data in this research was historical company data in the form of machine damage data, preventive maintenance implementation, and machine uptime.

The data was used in this research that was primary data and secondary data obtained from PT. XYZ. Primary data was collected through direct observation of the continuous frying machine and semi-structured interviews with the maintenance supervisor and maintenance technicians. These activities were carried out to verify the machine operating conditions, to identify the functions of the components, to identify the causes and effects of failures and to verify the history maintenance records. The secondary data were the historical maintenance records of the continuous frying machine from January 2021 to January 2024.

The collected data were preventive and corrective maintenance reports, machine operation time, production output, information of machine components and failure history. A total of 61 historical failure records were analyzed to determine the Time to Failure (TTF), Time to Repair (TTR), component criticality and maintenance intervals. Historical maintenance records were validated with the maintenance supervisor and field observations to ensure data reliability before being used in the analysis. These validated data then formed the basis for the FMECA, Reliability-Centered Maintenance (RCM) and reliability analyses. The probability distribution of the TTF and TTR data for each critical component was identified by evaluating several candidate distributions. The best fitting distribution was selected based on the goodness-of-fit test results. The selected distribution was used to estimate the MTTF and MTTR values needed for maintenance interval calculations.

Research framework is shown in Figure 1. The method used in this research was Failure Mode Effect and Critical Analysis (FMECA) to identify failure modes, failure effects and component criticality classification as well as system reliability analysis [8]. FMECA analysis was divided into two phases, namely FMEA by calculating the RPN value and critical analysis (CA) with a critical matrix as shown in Figure 2 [9].

Then, the FMECA method was combined with RCM to design maintenance activities by specifying maintenance actions (task selection). Then, the maintenance time interval is calculated by calculating the mean time to failure (MTTF) and mean time to repair (MTTR) values based on the type of failure data distribution. Data distribution types included Weibul, Normal, Lognormal and Exponential. From the MTTF value, reliability and availability system are calculated using the following equation [10].

Weibul Distribution:

$$MTTF/MTTR = \theta \Gamma \left( 1 + \frac{1}{\beta} \right) \quad (1)$$

Normal Distribution:

$$MTTF/MTTR = \mu \quad (2)$$

Lognormal Distribution:

$$MTTF/MTTR = t_{med} e^{\left(\frac{s^2}{2}\right)} \quad (3)$$

Exponential Distribution:

$$MTTF/MTTR = \frac{1}{\lambda} \quad (4)$$

Reliability Serial System:

$$R_s(t) = R_1(t) \times R_2(t) \dots \times R_n(t) \leq \min\{R_1(t), R_2(t), \dots, R_n(t)\} \quad (5)$$

Availability:

$$A = \frac{MTTF}{MTTF + MTTR} \quad (6)$$

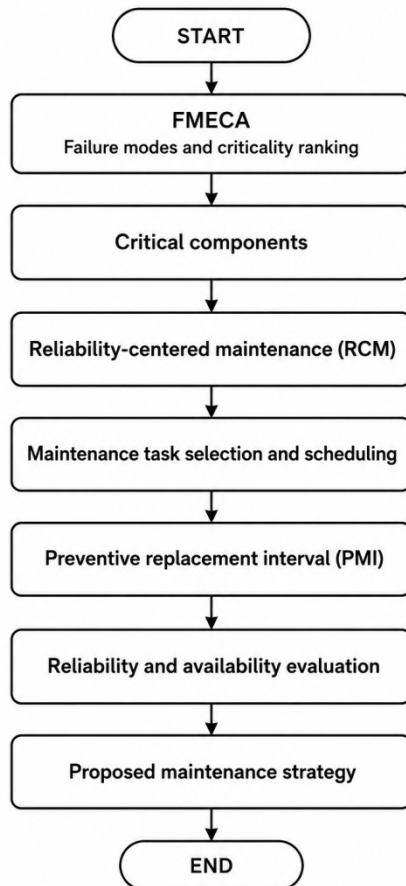


Figure 1: Methodology framework

| Frequency/<br>Consequence |              | Occurance     |              |              |              |              |
|---------------------------|--------------|---------------|--------------|--------------|--------------|--------------|
|                           |              | Very Unlikely | Remote       | Occasional   | Probable     | Frequent     |
| Severity                  | Catastrophic | Unacceptable  | Unacceptable | Unacceptable | Unacceptable | Unacceptable |
|                           | Critical     | Unacceptable  | Unacceptable | Unacceptable | Unacceptable | Unacceptable |
|                           | Moderate     | Unacceptable  | Unacceptable | Unacceptable | Unacceptable | Unacceptable |
|                           | Low          | Unacceptable  | Unacceptable | Unacceptable | Unacceptable | Unacceptable |
|                           | Minor        | Unacceptable  | Unacceptable | Unacceptable | Unacceptable | Unacceptable |

Acceptable  
 Tolerable  
 Unacceptable

Figure 2: Critical matrix

### 3. RESULTS AND DISCUSSION

#### 3.1 Failure Mode Effect and Critical Analysis (FMECA)

The FMECA was used to identify failure modes, failure effects, and criticality ratings for continuous fryers. The FMECA analysis process carried out consists of two phases: FMEA and CA. FMEA analysis includes identifying the system, creating a block diagram of the system functions, and searching for failure modes and the effects they cause. In addition, FMEA analysis also aims to obtain ranking values for each element factor, namely severity, occurrence and detection. Next, a critical component analysis was performed using a critical matrix using severity and occurrence ranking values converted to severity and occurrence levels [11]. The result of a critical analysis using FMECA is depicted in Table 1.

Based on the FMECA analysis, the critical components in the machine continuous frying are wire mesh network reached the "catastrophic" severity level with a downtime of  $\geq 8$  hours and the "occasional occurrence" severity level with occasional damage. Repairing wire mesh components takes quite a long time due to time spent draining oil, cooling components and availability of spare parts. From the FMECA analysis, an impact assessment was performed, which was obtained by the LTA to determine the priority of each failure mode and to check functional failures to ensure that not every failure mode was the same. The categories in LTA were safety problem (A), outage problem (B), economic problem (C) and hidden failure (D) [12]. Then, it was done task selection then carried out to find out the optimal action for the error mode that occurs. The action selection process was carried out considering the failure mode and through direct discussions with the head of the maintenance department. The RCM decision worksheet for continuous frying machine can be seen in Table 2.

Figure 3 illustrates the criticality matrices of the critical components selected from the FMECA findings. Each matrix maps the failure modes according to their severity and occurrence levels thus allowing their classification into acceptable, tolerable and unacceptable risk categories. The analysis results show that the failure modes related to the wire mesh fall into the unacceptable region, indicating the highest maintenance priority, while the other critical components were generally classified as tolerable. These criticality classifications were the basis for the selection of appropriate maintenance tasks in the RCM analysis is as shown in Table 2.

Table 1: Critical priority machine continuous frying

| Critical Priority | Functional Failure               | Sub-component             | RPN | Criticality  |
|-------------------|----------------------------------|---------------------------|-----|--------------|
| 1                 | Wire mesh rolling deformation    | Wire mesh take-out system | 100 | Unacceptable |
| 2                 | Wire mesh rupture                | Wire mesh take-out system | 120 | Unacceptable |
| 3                 | Motor burnout due to overheating | Pedal system              | 147 | Tolerable    |
| 4                 | Chain joint breakage             | Pedal system              | 120 | Tolerable    |
| 5                 | Scrubber motor burnout           | Drum filter               | 70  | Tolerable    |
| 6                 | Motor cable failure              | Pedal system              | 70  | Tolerable    |
| 7                 | Motor malfunction                | Drum filter               | 56  | Tolerable    |
| 8                 | Screw component failure          | Drum filter               | 50  | Tolerable    |
| 9                 | Teflon liner detachment/failure  | Drum filter               | 50  | Tolerable    |
| 10                | Pump leakage                     | Circulation pump          | 48  | Tolerable    |
| 11                | Shaft breakage                   | Wire mesh take-out system | 48  | Tolerable    |
| 12                | Gearbox leakage                  | Wire mesh take-out system | 48  | Tolerable    |
| 13                | Frame cracking                   | Frame structure           | 45  | Tolerable    |
| 14                | Shaft displacement/failure       | Drum filter               | 42  | Tolerable    |
| 15                | Body deformation (dent)          | Drum filter               | 40  | Tolerable    |
| 16                | Gearbox shaft breakage           | Pedal system              | 40  | Tolerable    |
| 17                | Drive chain wear                 | Pedal system              | 40  | Tolerable    |
| 18                | Oil pipe failure                 | Piping system             | 30  | Tolerable    |
| 19                | Drum leakage                     | Drum filter               | 30  | Tolerable    |
| 20                | Gearbox bolt housing cracking    | Drum filter               | 30  | Tolerable    |
| 21                | Valve blockage                   | Circulation pump          | 30  | Tolerable    |
| 22                | Coupling thread wear             | Circulation pump          | 30  | Tolerable    |
| 23                | Bent gearbox shaft               | Pedal system              | 30  | Tolerable    |
| 24                | Wire mesh drive chain skipping   | Wire mesh take-out system | 30  | Tolerable    |
| 25                | Drive chain breakage             | Wire mesh take-out system | 30  | Tolerable    |
| 26                | Leakage                          | Lacos system              | 20  | Tolerable    |
| 27                | Solenoid valve failure           | Three-way valve system    | 20  | Tolerable    |
| 28                | Drive gear key wear              | Pedal system              | 20  | Tolerable    |
| 29                | Chain derailment from track      | Pedal system              | 20  | Tolerable    |
| 30                | Motor mounting bracket failure   | Pedal system              | 20  | Tolerable    |
| 31                | Shaft jamming                    | Wire mesh take-out system | 20  | Tolerable    |

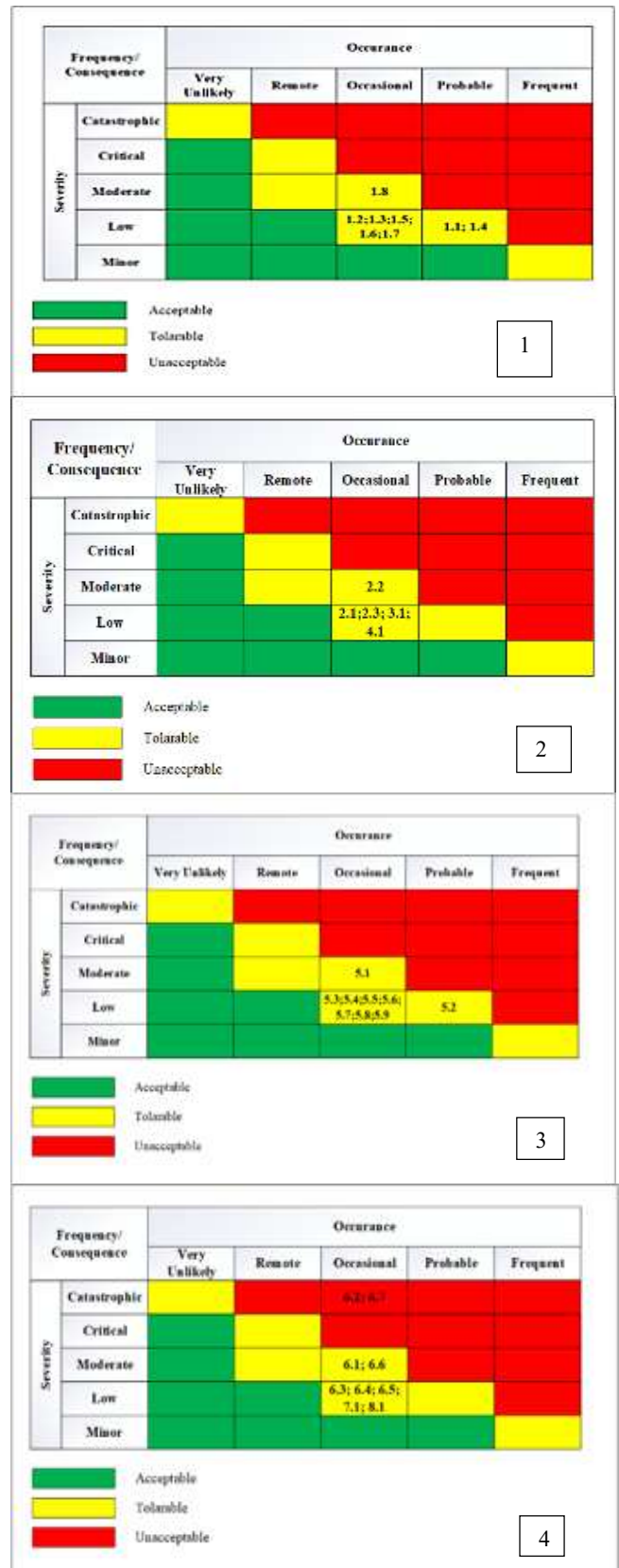


Table 2: RCM decision worksheet

| RCM Decision Worksheet    |                                          | Consequence evaluation |   |   |   | H<br>1 | H<br>2 | H<br>3 | Default action |        |        | Proposed Task              |
|---------------------------|------------------------------------------|------------------------|---|---|---|--------|--------|--------|----------------|--------|--------|----------------------------|
|                           |                                          |                        |   |   |   | S<br>1 | S<br>2 | S<br>3 |                |        |        |                            |
| Information Reference     |                                          |                        |   |   |   | O<br>1 | O<br>2 | O<br>3 |                |        |        |                            |
| Sub system                | Functional Failure                       | H                      | S | E | O | N<br>1 | N<br>2 | N<br>3 | H<br>4         | H<br>5 | S<br>4 |                            |
| Drum Filter               | Motor burn out due to over heating       | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Screw component failure                  | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Teflon liner detachment/failure          | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
|                           | Shaft displacement/failure               | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
|                           | Drum leakage                             | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
|                           | Scrubber motor burnout                   | N                      | Y | N | N | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Gearbox bolt housing cracking            | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Body deformation/dent                    | N                      | Y | Y | Y | N      | Y      | N      | -              | -      | -      | Schedule restoration task  |
| Circulation Pump          | Coupling thread wear                     | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Pump leakage                             | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Valve blockage                           | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
| Lacos                     | Leakage                                  | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
| Three-way Valve           | Solenoid valve malfunction               | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
| Pedal System              | Gearbox shaft breakage or bending        | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
|                           | Motor burnout due to over-heating        | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Drive gear key wear                      | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Chain wear, breakage, or derailment      | N                      | Y | Y | Y | N      | Y      | N      | -              | -      | -      | Schedule restoration task  |
|                           | Motor cable failure                      | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
|                           | Motor mounting bracket failure           | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
| Wire Mesh Take-Out System | Shaft breakage or jamming                | N                      | Y | Y | Y | N      | Y      | N      | -              | -      | -      | Schedule restoration task  |
|                           | Wire mesh rolling deformation or rupture | N                      | Y | Y | Y | N      | Y      | N      | -              | -      | -      | Schedule restoration task  |
|                           | Chain skipping or breakage               | N                      | Y | Y | Y | N      | Y      | N      | -              | -      | -      | Schedule restoration task  |
|                           | Gearbox leakage                          | N                      | Y | Y | Y | N      | N      | Y      | -              | -      | -      | Schedule discard task      |
| Frame                     | Cracking                                 | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |
| Oil Pipe                  | Leakage                                  | N                      | Y | Y | Y | Y      | N      | N      | -              | -      | -      | Schedule on condition task |

### 3.2 Determine the type of data distribution

From the Time Between Failures (TTF) and Time Between Repairs (TTR) data, the appropriate distribution type was determined using the least squares method by calculating index of fit [13].

$$r = \frac{n \sum_{i=1}^n X_i Y_i - (\sum_{i=1}^n X_i \sum_{i=1}^n Y_i)}{\sqrt{n [\sum_{i=1}^n X_i^2 - (\sum_{i=1}^n X_i)^2]} \sqrt{n [\sum_{i=1}^n Y_i^2 - (\sum_{i=1}^n Y_i)^2]}} \quad (7)$$

Table 3: Index of fit TTR and TTF

| Component        | TTR                  | TTF                  |
|------------------|----------------------|----------------------|
|                  | Distribution r-value | Distribution r-value |
| Drum Filter      | Exponential 0.982    | Lognormal 0.976      |
| Circulation Pump | Exponential 0.969    | Normal 0.954         |
| Pedal System     | Lognormal 0.931      | Lognormal 0.965      |
| Wire Mesh System | Exponential 0.963    | Weibull 0.959        |

This means that can be obtained a range of distribution channels and seals of approval to achieve these distribution channels. Uji goodness of fit was developed for all data from TTR and TTF tested by Bartlett, Kolmogorov Smirnov and Mann. After the goodness-of-fit test, parameter calculations were performed for each selected distribution representing TTR and TTF data. The calculations were carried out using the MLE method (Maximum Likelihood Estimator). Table 4 showed the results of the fitness test for distribution types and estimated parameter values.

Table 4: Selected distribution

| Component        | Selected Distribution |            | Parameter Estimation             |                                         |
|------------------|-----------------------|------------|----------------------------------|-----------------------------------------|
|                  | TTR                   | TTF        | TTR                              | TTF                                     |
| Drum Filter      | -                     | Log-normal | -                                | $s = 1.19$<br>$t_{med} = 1126.48$       |
| Circulation Pump | Log-normal            | Normal     | $s = 0.205$<br>$t_{med} = 1.032$ | $\mu = 4483.267$<br>$\sigma = 3215.417$ |
| Pedal System     | Log-normal            | Log-normal | $s = 0.450$<br>$t_{med} = 1.367$ | $s = 0.705$<br>$t_{med} = 1931.509$     |
| Wire Mesh System | Exponential           | Weibull    | $\lambda = 0.251$                | $\beta = 0.720$<br>$\theta = 872.472$   |

### 3.3 Calculation of MTTR and MTTF values

The MTTR and MTTF calculations were performed using the estimated parameter values determined, depending on the type of data distribution. However, data that did not follow the specified distribution type were calculated using the following nonparametric method.

$$\widehat{MTTR} = \sum_{i=1}^n \frac{t_i}{n} \quad (8)$$

Table 5: MTTR and MTTF

| Component        | MTTR (hours) | MTTF (days) |
|------------------|--------------|-------------|
| Drum Filter      | 1.146        | 95.32       |
| Circulation Pump | 1.054        | 186.803     |
| Pedal System     | 1.513        | 103.201     |
| Wire Mesh System | 3.984        | 44.853      |

### 3.4 Calculation of Total Minimum Downtime

After an appropriate distribution was calculated and the MTTR and MTTF values were computed, the preventative replacement intervals were calculated to minimize downtime. The analyzed component was the circulation pump TTF data, which is normally distributed with MTTF values at intervals of 4483.267 hours or 95.32 days. Meanwhile, the TTF data has a lognormal distribution with a value of MTTR =  $T_f = T_p = 1.054$  hours. A summary of how to calculate preventive replacement intervals by minimizing downtime of circulation pump components can be found in Table 6 [11].

$$M(t) = \left( \frac{MTTF}{F(t)} \right) \quad (9)$$

$$M(4300) = \frac{4483.267}{0.47727} = 9393.486$$

$$D(tp) = \left( \frac{T_p \cdot R(t) + T_f \cdot (F(t))}{(t + T_p) \cdot R(t) + [M(t) + T_f] \cdot (F(t))} \right) \quad (10)$$

$$D(4300) = 0.000156565$$

$$Availability = 1 - D(tp) \quad (11)$$

$$Availability = 1 - 0.000156565 = 0.99984$$

atau 99.98%

The advantages of integrating FMECA and RCM over the previously established fixed-interval preventive maintenance policy were illustrated. These results were consistent with recent studies that showed the performance improvement of equipment by reliability-centered maintenance through risk-based maintenance planning and optimized maintenance intervals. Moreover, recent studies have been shown that combining reliability analysis and maintenance decision making can provide a more systematic approach to maintenance optimization. This study differs from the previous studies that mainly applied FMECA or RCM separately. This study combines component criticality analysis and reliability-based maintenance interval determination with actual industrial failure data. It provides a systematic maintenance framework for continuous frying machines [14,15].

From the calculation results using downtime minimization criteria, an optimal preventive replacement interval for circulation pump components was 4300 hours or 179 days with an increased availability of 99.8%. These results were consistent with Silva et al. [15] that showed reliability-based maintenance planning improves equipment performance by combining failure criticality with maintenance optimization [15]. Similarly, Geisbush and Ariaratnam emphasized the RCM's capability to enable more efficient maintenance scheduling than traditional time-based maintenance [14].

Table 6: Total minimum downtime

| tp   | F(t)    | R(t)    | $T_p \cdot R(t)$ | $T_f \cdot F(t)$ | M(t)     | D(t)        |
|------|---------|---------|------------------|------------------|----------|-------------|
| 3000 | 0.32229 | 0.67771 | 0.714303984      | 0.339696         | 13910.56 | 0.00016172  |
| 3100 | 0.33353 | 0.66647 | 0.702463922      | 0.351536         | 13442.04 | 0.000160906 |
| 3200 | 0.34491 | 0.65509 | 0.690464396      | 0.363536         | 12998.35 | 0.000160168 |
| 3300 | 0.35644 | 0.64356 | 0.678315017      | 0.375685         | 12577.99 | 0.000159502 |
| 3400 | 0.36810 | 0.63190 | 0.666025802      | 0.387974         | 12179.58 | 0.000158907 |
| 3500 | 0.37988 | 0.62012 | 0.65360716       | 0.400393         | 11801.82 | 0.000158383 |
| 3600 | 0.39177 | 0.60823 | 0.641069859      | 0.41293          | 11443.49 | 0.000157928 |
| 3700 | 0.40377 | 0.59623 | 0.628425         | 0.425575         | 11103.48 | 0.00015754  |
| 3800 | 0.41586 | 0.58414 | 0.615683988      | 0.438316         | 10780.72 | 0.000157218 |
| 3900 | 0.42803 | 0.57197 | 0.602858502      | 0.451141         | 10474.24 | 0.000156962 |
| 4000 | 0.44027 | 0.55973 | 0.589960464      | 0.46404          | 10183.11 | 0.000156769 |
| 4100 | 0.45256 | 0.54744 | 0.577002         | 0.476998         | 9906.464 | 0.00015664  |
| 4200 | 0.46490 | 0.53510 | 0.563995414      | 0.490005         | 9643.509 | 0.000156572 |
| 4300 | 0.47727 | 0.52273 | 0.550953146      | 0.503047         | 9393.486 | 0.000156565 |
| 4400 | 0.48967 | 0.51033 | 0.53788774       | 0.516112         | 9155.689 | 0.000156617 |
| 4500 | 0.50208 | 0.49792 | 0.524811809      | 0.529188         | 8929.457 | 0.000156729 |
| 4600 | 0.51448 | 0.48552 | 0.511737994      | 0.542262         | 8714.17  | 0.000156899 |
| 4700 | 0.52687 | 0.47313 | 0.49867893       | 0.555321         | 8509.246 | 0.000157125 |
| 4800 | 0.53923 | 0.46077 | 0.485647211      | 0.568353         | 8314.138 | 0.000157407 |
| 4900 | 0.55156 | 0.44844 | 0.47265535       | 0.581345         | 8128.334 | 0.000157745 |
| 5000 | 0.56384 | 0.43616 | 0.459715747      | 0.594284         | 7951.352 | 0.000158136 |

### 3.5 Calculation of Reliability and Availability Values

Reliability calculations were carried out to determine whether the system was functioning as intended. Component reliability values were calculated using a formula that fits the selected distribution. The equation can be used to calculate the reliability values for each distribution. System reliability calculations were performed for machines connected in series because the failure of any component can affect the functioning of the system use equation (5) and (6). System reliability was evaluated based on the component, current reliability (R), and proposed reliability (R), as shown in the Table 7. Based on Table 7, the results indicate a significant increase in reliability of all components following the implementation of the proposed maintenance policy. The reliability of the Drum Filter rose from 0.2759 to 0.601, the Circulation Pump from 0.5000 to 0.608, the Pedal System from 0.3622 to 0.605, and the Wire Mesh System from 0.3125 to 0.602.

These improvements demonstrate that the proposed maintenance policy enhances the probability of each component operating without failure during the specified operational period. The Drum Filter experienced the largest relative increase, while the Circulation Pump remained the component with the highest reliability under the proposed conditions. Most significant was the improvement in system reliability, which rose from 0.016 to 0.133. Hence, it was an increased approximately 8.31 times compared to the current condition. Although the system reliability value remains relatively low, this improvement demonstrates that integrating the proposed maintenance strategy positively impacts overall

system reliability and has the potential to reduce the risk of operational failure.

To calculate availability using the suggested MTTF and MTTR values. The initial availability of the continuous frying machine was 0.551 and the availability with the suggested maintenance interval is shown in Table 8. Based on the data in the Table 8, the application of the proposed MTTF indicates that maintenance intervals for all components were set shorter than the actual MTTF, reflecting a more conservative preventive maintenance strategy aimed at reducing the risk of component failure. The Drum Filter has an actual MTTF of 2,287.740 hours, which was set to a proposed MTTF of 830 hours, with an MTTR of 1.146 hours and an availability of 0.998621. The Circulation Pump has an actual MTTF of 4,483.267 hours and a proposed MTTF of 3,600 hours, achieving the highest availability at 0.999707 with an MTTR of 1.054 hours.

Table 7: Reliability system

| Component              | Current Reliability (R) | Proposed Reliability (R) |
|------------------------|-------------------------|--------------------------|
| Drum Filter            | 0.2759                  | 0.601                    |
| Circulation Pump       | 0.5000                  | 0.608                    |
| Pedal System           | 0.3622                  | 0.605                    |
| Wire Mesh System       | 0.3125                  | 0.602                    |
| System Reliability (R) | 0.016                   | 0.133                    |

Table 8: Availability system

| Component           | Actual MTTF | Proposed MTTF | MTTR (hours) | Availability |
|---------------------|-------------|---------------|--------------|--------------|
| Drum Filter         | 2,287.740   | 830           | 1.146        | 0.998621     |
| Circulation Pump    | 4,483.267   | 3,600         | 1.054        | 0.999707     |
| Pedal System        | 2,477.034   | 1,600         | 1.513        | 0.999055     |
| Wire Mesh System    | 1,076.467   | 340           | 3.984        | 0.988418     |
| System Availability | -           | -             | -            | 0.986        |

The Pedal System has an actual MTTF of 2,477.034 hours and a proposed MTTF of 1,600 hours, with an availability of 0.999055 and an MTTR of 1.513 hours. The Wire Mesh System shows the lowest availability performance at 0.988418, associated with a shorter proposed MTTF of 340 hours and the highest MTTR of 3.984 hours. Overall, these results demonstrate that setting a shorter proposed MTTF can support failure risk control through preventive maintenance. Therefore, the system availability value of 0.986 indicated the system as a whole maintains a high level of operational readiness. Wire mesh system was found to be the most crucial part as it had the highest number of failures like wire mesh rupture, deformation, chain disengagement and shaft failure. These failure modes interrupt the frying process directly and require immediate corrective actions, leading to production downtimes. Therefore, in the RCM analysis, the wire mesh was given priority to determine an appropriate preventive maintenance interval.

#### 4. CONCLUSION

According to the results of the research carried out, the critical component of the continuous fryer machine was the wire-mesh, which falls into the “unacceptable” category. The suggested maintenance interval based on reliability was 35 days for Drums Filter, the schedule discard tasks on the motor, screw and gear box bolt housing then schedule condition tasks on Teflon, as, drum components, and schedule restoration tasks on body components by adjusting the axle and bearings. On the Circulation Pump the recommended time interval was 150 days with action schedule discard task on coupling thread wear, pump leakage and valve blockage. For Pedal System, the recommended interval was 67 days with details of the schedule conditions task on the transmission and motorcycle components, frame, oil pipe then the schedule of the discard task on the motorcycle components and cables, and then the schedule recovery task on the chain. For Wire-Mesh System, the recommended time interval was 14 days with details of the schedule restoration tasks on the ash, wire-mesh, chain and gear components. This proposal increased reliability by 0.016 to 0.133 and availability to 0.986 or 98.6%. Additionally, preventive replacement intervals with minimum downtime criteria can increase pump component availability to 99.8%. Future work should focus on validating the proposed FMECA- and RCM-based maintenance intervals through long-term operational data, while integrating condition-based and predictive maintenance to further improve reliability, availability, minimize downtime, and reduce maintenance costs, particularly for the critical Wire-Mesh System.

#### ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the management and maintenance team for their valuable support, technical assistance, and contribution during the data collection process. The authors also acknowledge the guidance and support from all parties involved in this research.

#### REFERENCES

- [1] Sari, D.P. & Ridho, F. (2016). Evaluasi manajemen perawatan dengan metode Reliability Centered Maintenance (RCM) II pada mesin blowing I di Plant I PT. Pisma Putra Textile. *Jurnal Teknik Industri*, 11(2).
- [2] Wulandari, R.E., Aksioma, D.F. & Haryono. (2018). Analisis keandalan dan availabilitas pada mesin produksi lampu pijar sistem seri menggunakan pendekatan analisis Markov di PT. Sinar Angkasa Rungut. *Jurnal Sains dan Seni ITS*, 7(2).
- [3] Ardian, A. (2017). *Handout Perawatan dan Perbaikan Mesin*. Yogyakarta, Indonesia: Fakultas Teknik Universitas Negeri Yogyakarta.
- [4] Supriyanto, H., Kurniati, N. & Supriyanto, M.F.R. (2021). Maintenance performance evaluation of an RCM implementation: A functional oriented case study. *International Journal of Mechanical Engineering and Robotics Research*, 10(12), 702–709. doi:10.18178/ijmerr.10.12.702-709.
- [5] Fang, F., Zhao, Z.J., Huang, C., Zhang, X.Y., Wang, H.T. & Yang, Y.J. (2019). Application of reliability-centered maintenance in metro door system. *IEEE Access*, 7, 186167–186174. doi:10.1109/ACCESS.2019.2960521.
- [6] Yavuz, O., Doğan, E., Carus, E. & Görgülü, A. (2019). Reliability centered maintenance practices in food industry. *Procedia Computer Science*, 158, 227–234. doi:10.1016/j.procs.2019.09.046.
- [7] Soltanali, H., Khojastehpour, M. & Farinha, J.T. (2022). An improved risk and reliability framework-based maintenance planning for food processing systems. *Quality Technology & Quantitative Management*, 19(3). doi:10.1080/16843703.2022.2093565.
- [8] Dixon, J. & Gullo, L.J. (2021). *Design for Maintainability*. 1st ed. John Wiley & Sons Ltd.
- [9] Dzulyadain, H., Budiasih, E., Tatas, F. & Atmaji, D. (2020). Usulan kebijakan perawatan pada mesin press di PT XYZ menggunakan metode Reliability Centered Maintenance (RCM II) dan analisis FMECA. *Undergraduate thesis/Report*, Telkom University.
- [10] Tsarouhas, P. (2020). Reliability, availability, and maintainability (RAM) study of an ice cream industry. *Applied Sciences*, 10(12). doi:10.3390/app10124265.
- [11] Manzini, R., Regattieri, A., Pham, H. & Ferrari, E. (2010). *Maintenance for Industrial Systems*. London, UK: Springer London. doi:10.1007/978-1-84882-575-8.
- [12] Moubray, J. (1997). *Reliability Centered Maintenance*. 2nd ed. British Library Cataloguing.
- [13] Ebeling, C.E. (2010). *An Introduction to Reliability and Maintainability Engineering*. 2nd ed. Waveland Press Inc.
- [14] Geisbush, J. & Ariaratnam, S.T. (2023). Reliability centered maintenance (RCM): Literature review of

current industry state of practice. *Journal of Quality in Maintenance Engineering*, 29(2), 313–337.  
doi:10.1108/JQME-02-2021-0018.

[15] Silva, R.F., Melani, A.H.A., Michalski, M.A.C. & Souza,

G.F.M. (2023). Reliability and risk centered maintenance: A novel method for supporting maintenance management. *Applied Sciences*, 13(19), 10605.  
doi:10.3390/app131910605.