Maintenance of automatic valve parts in soy blending tanks using the reliability centred maintenance method at PT KHAI

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ABSTRACT

In the manufacturing industry, effective machine maintenance is essential to ensure production continuity and prevent downtime. PT KHAI faces performance degradation and damage to the Automatic Valve parts in its soy blending tanks, leading to significant production losses. This study analyzes the maintenance of these components using the Reliability Centered Maintenance (RCM) method. The novelty of this research lies in its specific application to Piston Actuated Butterfly Valves within the liquid handling systems of the food processing industry, a specialized area that remains under-explored compared to heavy machinery or power plant sectors. The methodology involves system identification, Failure Mode and Effect Analysis (FMEA), Logic Tree Analysis (LTA), and Task Selection. The results identify critical failure components, including actuators, bearings, seals, packing valves, solenoid valves, limit switches, and control systems. The proposed maintenance strategy consists of Time Directed tasks for four components, Condition Directed for one component, and Finding Failure for three components. In conclusion, this study provides a new framework for mitigating hidden failures in automated actuation systems, offering a replicable maintenance model for ensuring high-hygiene production efficiency in the food industry.

1. Introduction

Industry is an economic activity that processes raw materials, raw materials, semi-finished goods or finished goods into high-value goods (Azwir et al., 2020). In 2014, on a national scale, this sector contributed in the form of an increase in the economy by 20.27% by shifting the role of Commodity Based to Manufacture Based (Masruri, 2023). With the presence of the times in the field of technology and industry, equipment has become a common thing to encounter but has a complex function in production activities. This equipment is the reason why a product can be produced, have quality, and be highly competitive (Samharil et al., 2022). However, the equipment used certainly has a limited service life and can be damaged at any time. Therefore, maintenance is an option in ensuring reliability, efficiency, and operational safety (Prastiawan et al., 2021).

Previous research conducted by (Azhari et al., 2024), using the RCM method in the analysis of ship maintenance by obtaining the results of 3 components, namely those found in the three components of the pipeline, namely fuel pipes, oil, and engine cooling. In Failure Finding (FF), 4 components were obtained, namely those contained in the seachast, injector pump, fuel filter, and air components with recommended action proposals. The research was also conducted by (Pusakaningwati, 2023), this study applies the Reliability Centred Maintenance (RCM) Method in the maintenance management of the Distribution Control panel in the Tanngangce Building. The results of the check showed a decrease in the Risk Priority Number (RPN) value from 540 to 126, indicating the success of repair and replacement actions of components in significantly reducing the risk of failure. The research was also conducted by (Simanungkalit et al., 2023), using the RCM method with qualitative analysis results, there are 4 components of MSI (Maintenance Significant Item), namely mill bearing, mill diaphragm, mill fan and vibrating sensor. The research was conducted by (Yusuf et al., 2024), using the Reliability Centred Maintenance (RCM) method to determine critical components, determine the right Task Selection, and provide proposed improvements. Based on the results of RCM's research, critical components in the forming machine are Squeeze Top Roll components consisting of Bearings, Shafts, Sleeves, Cover Sleeves, and Roll Tops. The research was also conducted by (Purnomo et al., 2021), the Reliability Centred Maintenance method is a method used to reduce downtime that occurs at PT. Tristan Engineering. The results of the research obtained at PT. Tristan Engineering includes the absence of regular maintenance that causes damage to the x-ray engine components.

The main problem raised in this company is the problem of the maintenance and maintenance of automatic valve machine parts for soy blending tanks, with the increasing age, use and lack of maintenance making a machine will fail and cause inhibition of the production process and even losses for a company. In an Automatic Valve there are twelve parts that are used to support the valve's working process, one of which is the actuator, this actuator functions to convert the control signal into mechanical movement, moving the valve stem (stem) to open or close the disc or plug that regulates the flow. PT KHAI suffered losses due to the decrease in quality and quantity of production caused by the automatic valve of the soy blending tank which resulted in unexpected maintenance breakdown costs.

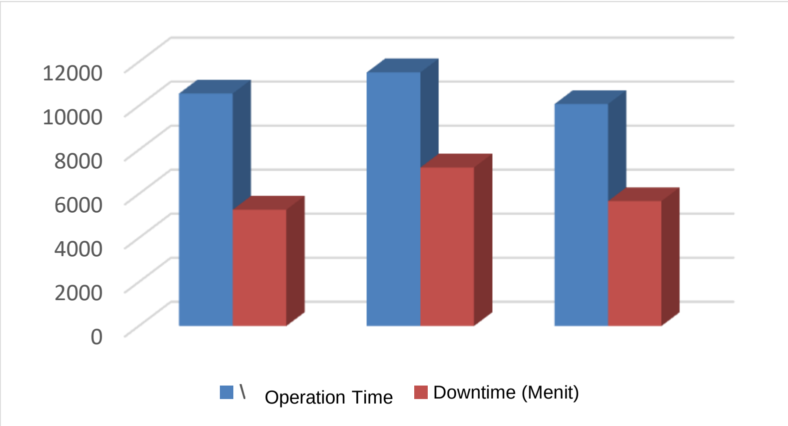

Fig. 1 Automatic valve part damage data.

To prevent losses and increase the life and efficiency of the engine, based on previous research, the Reliability Centred Maintenance (RCM) method will be used (Sodikin & Jati, 2022), RCM is a maintenance method for decision-making regarding maintenance tasks that includes reactive, proactive, and preventive maintenance practices to ensure that assets can operate properly based on the operational context (Setiadi & Al Faritsy, 2023).

This research makes an important contribution in increasing the effectiveness of engine maintenance using the Reliability Centred Maintenance (RCM) method, so as to minimize production downtime, extend the service life of Automatic Valve components, reduce the cost of sudden damage, and increase reliability and operational efficiency at PT KHAI. In addition, the results of this research can also be a reference for companies in developing a more systematic and structured preventive care system (Raharja & Suardika, 2021). While Reliability Centered Maintenance (RCM) has been extensively applied in various heavy industries such as automotive and marine engineering, its specific application to critical components like automatic valves in the food processing industry remains underexplored. Previous studies have not fully addressed the unique maintenance challenges of Piston Actuated Butterfly Valves in soy blending processes, where component failures directly lead to unpredicted breakdown maintenance costs and production losses. Therefore, this study aims to bridge this gap by applying the RCM method to: (1) identify critical failure modes and their risk priority

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levels using FMEA, (2) determine the root causes of failures through Logic Tree Analysis (LTA), and (3) formulate optimal maintenance strategies specifically distinguishing between Time Directed, Condition Directed, and Finding Failure tasks to enhance system reliability. By focusing on this specific equipment in a real-world manufacturing setting at PT KHAI, this research contributes a novel framework for minimizing downtime and optimizing maintenance decisions for liquid handling systems in the food and beverage industry.

While RCM has been widely adopted in heavy industries, its application focusing on the specific mechanisms of Piston Actuated Butterfly Valves within food production ecosystems remains under-represented in the literature. This study aims to bridge this research gap. The scientific contribution of this work lies in developing a failure mitigation model for automated actuation systems operating under high-hygiene requirements, where hidden failures often evade conventional maintenance schemes. By integrating FMEA, LTA, and Task Selection, this research provides not only practical industrial solutions but also new empirical evidence regarding the degradation characteristics of automatic valve components in liquid processing. These findings serve as a theoretical reference for designing more adaptive preventive maintenance strategies for similar equipment in the food industry sector.

2. Methods

Research Object

The object of research in this study is the Automatic Valve in the Soy Blending Tank at PT KHAI. Automatic valve functions to regulate the flow of fluid in the production process in the soy blending tank. Over the time of use and increasing service life, components in automatic valves experience a decrease in performance that can cause operational disruptions, downtime, and production losses. Therefore, this study is focused on the analysis of the maintenance and maintenance of critical components in the automatic valve system, using the Reliability Centred Maintenance (RCM) method to identify failure modes, determine the cause of failure, and provide recommendations for optimal maintenance strategies to improve machine reliability and production effectiveness (Fitri & Farid, 2023).

Data Collection Techniques

To support this research, data was collected using several techniques such as observation, interviews, documentation studies, and literature studies (Daruhadi & Sopiati, 2024). This observation is on the operational process of the Automatic Valve in the soy blending tank. This observation aims to understand the physical condition of components, maintenance procedures, and the frequency of engine failures and downtime in real time in the field. The historical machine usage data analyzed covers operational records over a three-month period (December 2023 – February 2024). This timeframe was selected to ensure that the data collected is representative in illustrating seasonal failure cycles and the degradation patterns of Automatic Valve components in the soy blending tanks at PT KHAI. Interviews were conducted with related parties, such as Maintenance Supervisors, production operators, and Engineering Maintenance teams. This interview aims to obtain in-depth information about the history of component damage, treatment strategies that have been applied, and evaluation of the effectiveness of previous treatments. This interview is unstructured to provide space for the interviewees to explain their experiences and knowledge more broadly. Documentation studies are also carried out as part of the data collection technique. The author studied various internal company documents, including historical machine downtime data, maintenance breakdown reports, automatic valve technical specifications, and maintenance activity logbooks. These documents provide quantitative and technical data that are essential to enrich the analysis. Literature study from various books, journals, and scientific articles that discuss the concepts of RCM, Failure Mode and Effect Analysis (FMEA), and Logic Tree Analysis (LTA). This literature study is the theoretical basis that strengthens the basis of analysis in this study.

Data Analysis Techniques

In this study, the data analysis technique was carried out using the Reliability Centred Maintenance method approach (RCM) (Hidayat et al., 2021). Data that has been collected through observation,

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interviews, documentation, and operational recording is analyzed through several systematic stages to determine the appropriate maintenance actions for automatic valve parts.

a. The system that became the object of the study was selected, namely the Automatic Valve type Electric Piston Actuated Butterfly Valve which is used in the Soy Blending tank. After that, the definition of system limits is carried out to ensure that the scope of analysis only covers critical parts of the automatic valve, such as actuators, bearings, seals, packing valves, solenoid valves, limit switches, and control systems.
b. Create system descriptions and Functional Block Diagrams (FDBs). This diagram maps the relationships between components and functional flows that occur in a valve system, so that it can be seen how a failure in one component can impact the entire system. Identification of malfunctions is carried out by detailing every potential damage to each component. After that, Failure Mode and Effect Analysis (FMEA) is applied to evaluate the risk level of each failure. Each failure is analyzed based on three main factors, namely Severity (severity), Occurrence (frequency of occurrence), and Detection (ease of detection). These three factors are used to calculate the Risk Priority Number (RPN) value, which is a reference in determining the priority of handling failures. The preparation of Failure Mode and Effect Analysis (FMEA) can find out what causes a system failure and the impact caused by the failure. RPN Calculation:

$$\text{RPN} = S \times O \times D \tag{1}$$

Information; S : Severity; O : Occurance; D : Detection

Table 1 is used to determine the Severity, Occurrenceance, and Detection scores of components that often fail.

Table 1 Indicator Failure Modes and Effect Analysis

Efect	Severity of Effects	Score
Dangerous (Very Serious)	Has an effect on safety in operation and violates government regulations without warning	10
Dangerous with stages	Have an effect on safety in operation and violation of government regulations with warnings	9
Very High	Product/item is not operating (loses its primary function)	8
High	Product/item operates but performance is reduced, customer is very dissatisfied	7
Keep	The product/item is operating but there is one thing that is not operating, the customer is not satisfied	6
Low	The product/item operates but there is one thing that decreases its performance, the customer is not satisfied	5
Very Low	Products/items operate defects for most customers	4
A little annoying	Product/item operating defect occurs for half of the customer	3
Very Few Disturbing	Product/item operation defects occur for very meticulous customers	2
No effect	Has no effect	1

Source: (Stamatis, 2003)

To determine the urgency of corrective actions, the calculated RPN scores are classified into three priority levels. These thresholds are established based on the distribution of historical failure data and manufacturing risk assessment standards, as follows:

1. High Priority (RPN > 200): Failure modes in this category are considered critical due to their significant impact on production lines or high safety risks. Immediate corrective actions or revisions to the maintenance schedule are mandatory.
2. Medium Priority (100 ≤ RPN ≤ 200): These failures indicate moderate risks that require regular monitoring and scheduled preventive maintenance to prevent escalation.
3. Low Priority (RPN < 100): Failure modes in this category present low risks with minimal impact on the overall system. Recommended actions are limited to routine maintenance or periodic observation.

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c. After FMEA, Logic Tree Analysis (LTA) is carried out to classify failures based on their level of criticality, namely in the categories of safety problems, operational problems (outage problems), economic problems (economic problems), or hidden failures (hidden failures). With this approach, it is possible to determine the type of action that is most appropriate for each failure mode. The use of LTA aims to distinguish the impact of failures on occupational safety, production operations, and repair costs. The categorization criteria in this study are based on a decision tree that divides consequences into four main categories:
   1. Category A (Safety-Critical): Failures are classified into this category if they have a direct impact on operator safety or the environment. The specific criterion is if the potential workplace accident has a Severity (S) score ≥ 8 or if there is a risk of food contamination that violates the company's food safety standards
   2. Category B (Outage/Operational): Failures that do not impact safety but cause a total production line shutdown (downtime). This category is typically characterized by a high Occurrence (O) score and obstruction of fluid flow in the soy blending tanks
   3. Category C (Economic/Non-Operational): Failures that only impact spare part repair costs without significantly stopping the production process
   4. Category D (Hidden Failure): Failures in hidden functions that are not detected by operators under normal operational conditions (having a Detection (D) score ≥ 7), which, if left unaddressed, could trigger multiple system failures.

d. The final stage of analysis is task selection, which is the selection of the type of treatment action needed. Treatment actions are differentiated into Condition Directed (CD), Time Directed (TD), and Finding Failure (FF) based on the results of FMEA and LTA analysis. The determination of this action aims to extend the life of components, minimize production downtime, and improve the overall reliability of the system. Through this stage of analysis, this study produces recommendations for optimal maintenance actions for automatic valves in Soy Blending tanks at KHAI.

Fig. 2 presents the systematic research methodology flowchart, starting from literature review and field study, followed by problem formulation, data collection and processing, analysis and discussion, and concluding with the research conclusions.

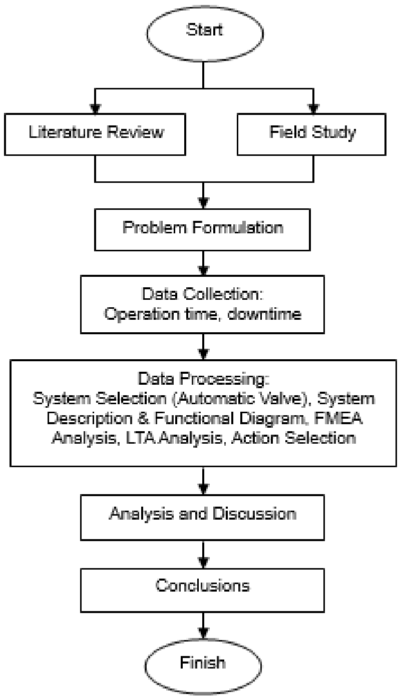

Fig. 2 Research flowchart.

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3. Results and Discussion

Table 2 presents the average frequency of machine utilization, including operating hours and downtime, over the observed period. The data show fluctuations in both operating time and downtime across different months. In the subsequent stage, a system description was conducted to identify the critical system design, analyze the relationships among system components, and evaluate their influence on the operational effectiveness and efficiency of the tank system. The collected information was then used to develop a functional block diagram to support a more detailed identification of component interactions and functional dependencies.

Table 2 Average frequency of machine use

No	Month	Operating Hours		Downtime (Minutes)
		Day	Minute	
1	Dec - 2023	22	10560	5280
2	Jan - 2024	24	11520	7200
3	Feb - 2024	21	10080	5670

Based on the operational data, a significant increase in downtime was observed in January 2024, reaching 7,200 minutes. This condition resulted from a combination of two main factors. First, January represents a peak production period aimed at fulfilling market demand following the year-end holidays, which caused the automatic valves to operate at a higher opening and closing frequency than under normal conditions. Second, the intensified operating load accelerated the degradation of critical components, particularly the seals and actuators, which were already approaching the wear-out phase of their service life. Consequently, unexpected failures occurred and required extended repair times due to the accumulation of hardened fluid residues inside the valves during high-output operations.

Fig. 3 illustrates the functional block diagram of the automatic valve system. As shown in the figure, the piston-actuated butterfly valve consists of 12 interrelated components that function as an integrated system. A failure in any single component can interrupt the operational sequence and cause the entire machine to cease operation.

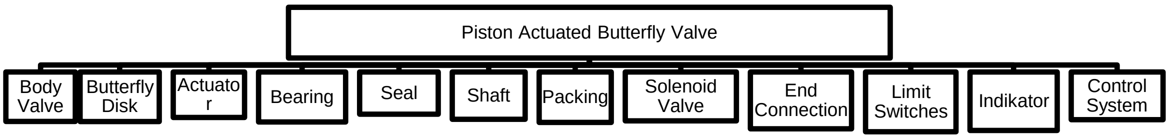

Fig. 3 Functional block diagram.

Determination of System Failure

An analysis was conducted to identify failures occurring in the automatic valve system. The results of the failure analysis, including component functions and observed failure modes, are summarized in Table 3. Table 3 shows that several components experienced functional degradation or failure, while others remained in normal operating condition. A total of eight failure modes were identified across the automatic valve system. Among these, the solenoid valve exhibited multiple failure modes, namely electrical malfunction and leakage, indicating a critical component with a higher failure severity.

Table 3 Failure analysis

Component	Function	Failure
Body Valve	Accommodates all internal components of the valve and connects the valve to the piping system	No damage
Buttefly Disk	Fluid flow inlets and outlets	No damage
Actuator	Automatically drive the valve using an electric motor (electric)	The actuator has an electrical fault
Bearing	Supporting part of the shaft in driving the rotation of the disc	Bearings suffer from friction wear
Seal	Inner valve that protects leaks around the disc when closed	*Seal is worn by friction*

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Component	Function	Failure
Shaft	Shaft The inner valve is connected to the disc, useful for rotating the disc	No damage
Valve Packing	Filler space around the valve shaft that prevents leakage to the outside of the valve	Packing Wear Packing has leaked
Solenoid Valve	Controls fluid flow into the actuator to drive the valve	Electrical failure Leaking
End Connection	The part of the valve that serves to connect the valve to the pipe in the piping system	No damage
Limit Switches	A switch that detects the physical position of a valve component, such as a butterfly disk or shaft	The switch is worn out
Indicator	Visually displaying valve position	No damage
Control System	Automatically regulates the operation process from the valve	Sensor failure

Implementation Failure Mode and Effect Analysis (FMEA)

FMEA was applied to identify and prioritize potential failure modes in the automatic valve system based on component functional analysis and maintenance records. As summarized in Table 4, several failure modes—particularly actuator electrical faults, bearing wear, seal degradation, packing wear, and worn switches—exhibited high RPN values and were classified as high-priority risks requiring immediate corrective actions. Other failure modes, including solenoid valve malfunctions and sensor failures, were categorized as medium-priority risks, indicating the need for preventive monitoring and maintenance.

Table 4 Failure Modes and Effect Analysis

No	Failure	Effects of Potential Failure	S	Potential Causes	O	Control	D	RPN	Priority
1	Electrical faults in the actuator	Automatic Valve is malfunctioned and cannot operate	9	Actuator Experiencing current leakage and short circuit	5	Stop Operations and perform inspections	6	270	High
2	Bearings are worn out	Valve movement gets jammed	8	The age of the bearing has passed the limit and the bearing material is not good	5	Replacing bearing parts with new ones	7	280	High
3	Seal is worn out	Valve leaks when closed	7	The age of the seal has passed the limit and the seal material is not good	6	Replacement of parts with new ones	6	252	High
4	Packing Wear	Leaks in the Stuffing Box Area	7	The age of the Packing has passed the limit and the seal material is not good	6	Replacement of parts with new ones	5	210	High
5	Electrical failure of solenoid valve	Valve cannot be opened or closed	9	Burning coil	4	Performs temperature observations and provides voltage regulators	5	180	Medium
6	Solenoid valve	Valve has a leak	9	Material Subjected to	4	Replacing the corroded solenoid	5	180	Medium

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No	Failure	Effects of Potential Failure	S	Potential Causes	O	Control	D	RPN	Priority
	leakage			Corrosion		part with a new one			
7	The switch is worn out	Valve position cannot be detected	7	Usage on excess	5	Replace the sensor periodically	6	210	High
8	Sensor failure	Valve position control disorder	8	Software failure connected with sensors	5	Check programming and configuration with sensors	4	160	Medium

Logic Tree Analysis

Logic Tree Analysis (LTA) aims to prioritize each fault mode and make observations of the functions and malfunctions of the components. The priority of a type or type of damage can be found by answering some of the questions that have been provided in the LTA. The LTA contains information regarding the number and name of the malfunction, the number and mode of damage, critical analysis and additional information needed (Sodikin & Jati, 2022). The LTA development process is illustrated in Fig. 4, while the results of the LTA applied to the automatic valve system of the soy blending tank are presented in Table 5.

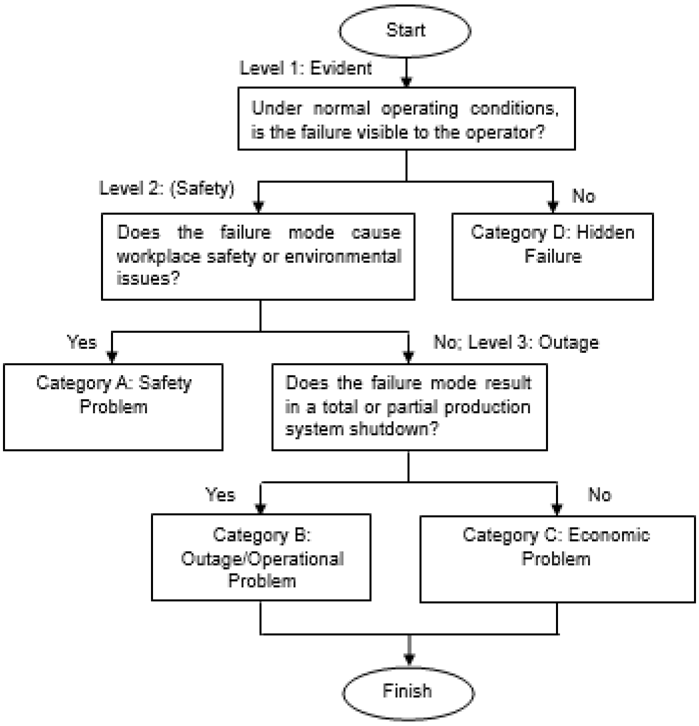

Fig. 4 Flowchart Logic Tree Analysis.

Table 5 *Logic Tree Analysis*

Failure	Effects of potential failure	Potential Causes	*Critically Analysis*[1]			
			E	S	O	C
Electrical faults in the actuator	Automatic Valve is malfunctioned and cannot operate	Actuator Experiencing current leakage and short circuit	Yes	Yes	Yes	A/B
Bearings are worn out	Valve movement gets jammed	The age of the bearing has passed the limit and the	No	No	Yes	B

[1] **E, S, O, C** are categorization codes used in Logic Tree Analysis (LTA) to classify failure consequences: **E** (Evident) refers to visible failures; **S** (Safety) denotes failures with safety or environmental impacts; **O** (Operational) indicates failures affecting production output; and **C** (Cost/Non-operational) refers to failures with purely economic implications

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Failure	Effects of potential failure	Potential Causes	Critically Analysis[1]			
			E	S	O	C
		bearing material is not good				
Seal is worn out	Valve leaks when closed	The age of the seal has passed the limit and the seal material is not good	Yes	Yes	No	B
Packing Wear	Leaks in the Stuffing Box Area	The age of the Packing has passed the limit and the seal material is not good	No	Yes	No	A/D
Electrical failure of solenoid valve	Valve cannot be opened or closed	Burning coil	No	No	Yes	B
Leakage solenoid valve	Valve has a leak	Material Subjected to Corrosion	No	Yes	No	A
The switch is worn out	Valve position cannot be detected	Usage on excess	Yes	No	Yes	B
Sensor failure	Valve position control disorder	Software failure connected with sensors	Yes	No	Yes	B

LTA shows that out of a total of 8 failure modes, 6 failure problems are in category B, then 2 are in category A, and the rest are in categories A/D and B/C. This shows that the failure that occurred in the automatic valve caused partial to complete engine shutdown, this is a bad sign because it can have an impact on the company's productivity. Not only that, safety issues also need to be considered considering that the actuator parts, solenoid valves, and, packing valves, if there is a failure above, can endanger the safety of workers.

Task Selection

Task selection represents the final stage of the Reliability Centred Maintenance (RCM) analysis, aiming to determine appropriate maintenance actions for each identified failure mode. The selection process was based on the integration of FMEA and LTA results. The resume of maintenance task selection for the automatic valve system is presented in Table 6.

Table 6 Task selection

No	Component Type	Failure	RPN	LTA	Task Selection
1	Actuator	Electrical faults in the actuator	270	A/B	*Finding Failure*
	Bearing	Bearings are worn out	280	B	Time Directed
3	*Seal*	Seal is worn out	252	B	Time Directed
4	*Packing Valve*	Packing Wear	120	A/D	Time Directed
5	*Solenoid Valve*	Electrical Failure	180	B	Time Directed
6	*Solenoid Valve*	Leakage solenoid Valve	180	A	Time Directed
7	Limit Switches	The switch is worn out	210	B/C	Time Directed
8	*Control System*	Sensor failure	160	B	Condition Directed

Based on the calculation results, the Actuator and Solenoid Valve components have the highest RPN values (above 200), placing them as the top priority. Interpretively, the high RPN value of the Actuator is not merely a mechanical figure but a representation of a fatal operational risk. A failure in the actuator causes the valve to fail in responding to control system signals, which in the soy blending process at PT KHAI results in inaccurate material composition or a total halt of fluid flow. The dominant cause of this failure was identified as material fatigue due to high workloads during the peak production period (January), which was exacerbated by residue accumulation that hindered mechanical movement. This is consistent with the findings of (Pusakaningwati, 2023), who stated that in food industry automation systems, components that interact directly with the actuation system tend to have a faster degradation rate due to high duty cycle frequencies. Furthermore, when compared to the study by (Simanungkalit et al., 2023), in the cement processing industry, there is a difference in

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criticality characteristics. In Simanungkalit's study, structural components often become a priority due to heavy equipment safety factors. However, in this research, criticality leans more towards Category B and Category A. This reinforces the contribution of this research that in the Automatic Valve system in the food industry, the economic impact due to production downtime and hidden functional failures is far more dominant than direct physical safety risks. The implementation of the proposed Time Directed strategy for these high-RPN components is a mitigation step to shift the failure pattern from reactive to proactive. By applying a periodic replacement schedule before the wear-out phase is reached, the company can minimize the potential downtime of 7,200 minutes as occurred during the January period.

Based on the results of the recapitulation table for the selection of actions in Reliability Centred Maintenance that have been carried out, the selection of actions for critical components in the Automatic Valve is as follows:

a. *Time Directed*
   It is an action taken to prevent direct damage to the source of damage to the equipment that refers to the time or age of the component. In the Time Directed condition, there are 4 components that use this action, namely Bearing, Seal, Packing Valve, and Limit Switches.
b. *Condition Directed*
   It is an action taken to detect damage by checking the tool. If the examination finds signs of damage, it needs to be followed up by repairing or replacing components. In Condition Directed (CD) there is 1 component that uses this action, namely the Control System.
c. *Finding Failure*
   It is an action that aims to find equipment damage that is accompanied by regular inspections. There are 2 components that use this action, namely the Actuator and Solenoid Valve.

The selection of maintenance strategies presented in Table 6 is scientifically grounded in the specific failure characteristics of each component analyzed through the RCM decision logic. Time Directed (TD) tasks were assigned to mechanical components prone to age-related degradation, specifically Bearings, Seals, Packing Valves, and Limit Switches. These components exhibit wear-out failure patterns where the probability of failure increases with operating time; thus, scheduled replacement or restoration is the most effective strategy to prevent functional failure before it occurs. Conversely, the Control System was assigned a Condition Directed (CD) task. As an electronic monitoring unit, it typically manifests potential failure symptoms such as erratic sensor readings or drift that can be detected through continuous monitoring or inspection before total failure occurs. Finally, Finding Failure (FF) tasks were deemed necessary for the Actuator and Solenoid Valve. These components are susceptible to 'hidden failures' (e.g., stuck mechanisms or coil burnout) that may not be evident to operators during normal operation. Therefore, periodic functional checks are required to verify their availability upon demand.

These findings align with previous studies, such as (Setiadi & Al Faritsy, 2023) on rice milling units, which emphasized that critical mechanical components subject to wear are best managed through scheduled maintenance (Time Directed). However, this study contributes to the body of knowledge by demonstrating that in food processing liquid handling systems specifically for automatic valves a significant portion of reliability relies on managing hidden failures in actuation systems via Finding Failure tasks, a distinction often less emphasized in general mechanical equipment studies.

4. Conclusion

Based on the previous analysis and discussion, the conclusion of the study is that the components that most often suffer damage are the components of the Actuator, Bearing, Seal, Packing Valve, Solenoid Valve, Limit Switches, and control system components. The strategy that can be carried out in automatic valve maintenance actions using the RCM method is Time Directed (TD), there are 4 out of 8 damages that use this action, namely damage to bearings, seals, packing valves, and limit switches. Condition Directed (CD) is 1 in 8 damage that uses this action, namely damage to the control system. Finding Failure (FF) there are 3 out of 8 damages that use this action, namely damage to the actuator, and 2 damage to the solenoid valve. The method of providing maintenance actions for the Time Directed (TD) category is in the form of providing a repair schedule and replacement of components based on the specified analysis. The method of providing action for the Condition Directed (CD) category is to conduct periodic inspections to prevent damage. As for the Finding

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Failure (FF) category, it is in the form of conducting regular inspections to find the source of the problem of the damage.

This study demonstrates that applying Reliability Centered Maintenance (RCM) to Piston Actuated Butterfly Valves effectively transitions maintenance practices from a reactive to a reliability-based preventative approach. The analysis concludes that maintenance strategies should be distributed according to the specific failure characteristics of the components: **Time Directed** tasks are dominant, recommended for four mechanical components (bearings, seals, packing valves, limit switches) subject to predictable wear; **Finding Failure** tasks are crucial for two components (actuators, solenoid valves) to detect hidden functional failures; and a **Condition Directed** task is assigned to the single control system unit. By implementing these targeted strategies, the risk of unpredicted downtime caused by hidden failures in the actuation system can be significantly mitigated. These findings provide a practical framework for maintenance planning in the food processing industry, highlighting that optimal valve reliability is achieved not by a one-size-fits-all schedule, but by distinguishing between age-related degradation and hidden failure modes, thereby ensuring continuous production efficiency.

Research Limitations This study has several limitations that should be acknowledged. First, the historical data collection was conducted over a relatively short duration (three months), which may not fully capture long-term failure variability or the complete impact of annual seasonal production cycles. Second, the research focus is limited to the Automatic Valve components within the soy blending tanks; thus, the findings may require adjustments if applied to different valve types or fluid systems in non-food industries. Finally, the FMEA scoring still contains elements of expert subjectivity, although a triangulation process was employed to minimize potential bias. Future Research Directions Based on these limitations, future research is encouraged to expand the scope of historical data to at least two years to achieve a more statistically accurate reliability profile. Furthermore, integrating the RCM framework with Internet of Things (IoT) for real-time condition monitoring such as vibration and temperature sensors on actuators is highly recommended. Future studies could also incorporate a detailed Maintenance Cost Analysis to calculate the Return on Investment (ROI) of transitioning from reactive to proactive maintenance strategies

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