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RCM-Based Maintenance Strategy for Coating Machine Downtime Reductione

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Abstract

The coating machine plays a critical role in pharmaceutical production because it affects coating uniformity, drying stability, product quality, and production continuity. However, maintenance studies on pharmaceutical coating machines are still limited, especially those that integrate reliability indicators, downtime dominance analysis, failure risk assessment, root cause analysis, and RCM decision logic into one structured maintenance framework. This study proposes an integrated RCM-based reliability decision framework to identify critical components and formulate maintenance priorities for reducing coating machine downtime at PT. Triyasa Nagamas Farma. The framework combines Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), Availability, Pareto analysis, Failure Mode and Effect Analysis (FMEA), Risk Priority Number (RPN), Fishbone Diagram, and internal operational benchmarking. The results showed that the coating machine experienced 12 failure events with a total downtime of 1,110 minutes, an MTBF of 743.92 minutes/failure, an MTTR of 92.50 minutes/failure, and an Availability of 88.94%. Pareto analysis indicated that the blower, spray gun/nozzle, and coating drum contributed 81.08% of total downtime. FMEA identified the blower as the most critical component, with the highest RPN value of 384 and the largest downtime contribution of 390 minutes. Internal benchmarking between March and April showed a 45.83% downtime reduction, a 125.21% increase in MTBF, a 24.17% decrease in MTTR, and a 10.76 percentage-point increase in Availability. The proposed strategy emphasizes preventive and condition-based maintenance through airflow inspection, filter cleaning, motor temperature monitoring, nozzle cleaning, control panel calibration, and coating drum inspection. This study contributes by providing a structured reliability-based maintenance priority framework for pharmaceutical coating machine operations.

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1. Introduction

Machine downtime remains a critical problem in manufacturing systems because it reduces effective production time, disrupts production schedules, increases maintenance cost, and raises the risk of quality problems. In pharmaceutical manufacturing, machine reliability becomes more important because production equipment must support stable process parameters and consistent product quality. One of the critical facilities in tablet production is the coating machine. This machine affects coating uniformity, drying stability, product appearance, product protection, and final product quality. When the coating machine fails, production can stop, output can decrease, defects can increase, and rework or material loss can occur. Therefore, downtime problems in coating machines should not only be viewed as repair issues, but also as reliability and asset management problems that influence operational continuity and product quality [1], [2], [3].

Maintenance strategy has developed from corrective maintenance toward preventive, condition-based, predictive, and reliability-centered approaches. Reliability Centered Maintenance (RCM) is one of the established approaches in reliability engineering because it determines maintenance tasks based on asset function, functional failure, failure mode, failure effect, and operational consequence [2], [4]. In an asset management perspective, maintenance decisions should support equipment performance, risk control, life cycle value, and organizational objectives [3]. Recent maintenance studies also show that predictive maintenance and Industry 4.0-based maintenance can improve equipment monitoring through sensor data, machine learning, and failure prediction models [5], [6], [7]. However, these advanced approaches usually require sufficient historical data, sensor availability, and digital infrastructure. In many industrial case conditions, especially when available data are still limited to downtime, failure frequency, repair time, and maintenance records, RCM remains relevant as a practical and structured decision framework.

Previous studies have applied RCM to various industrial machines. Syafei and Suhendar [2] used RCM and Maintenance Value Stream Map to support machine maintenance planning. Effendi et al. [8] applied RCM to a super mixer machine in the pharmaceutical industry to prevent electric motor bearing failure. Rifai et al. [4] used RCM to plan maintenance for a pressure reducing system. Putra and Puspitasari [9] analyzed plastic packaging production machine maintenance using RCM, while Simanungkalit et al. [10] combined RCM and FMEA to improve maintenance effectiveness in a cement mill. Other studies applied RCM to conveyor, slitting, lathe, and textile machines [11], [12], [13], [14]. These studies confirm that RCM can support critical component identification and maintenance prioritization. However, most of them still focus on general manufacturing equipment and present RCM as a sequential application of tools rather than as an integrated reliability decision framework.

Several studies have also used Pareto analysis, FMEA, Risk Priority Number (RPN), and Fishbone Diagram to identify dominant failures and root causes. Pareto analysis is useful to identify components with the highest downtime contribution [15]. Fishbone Diagram helps identify root causes based on man, machine, method, material, environment, and measurement factors [16]. FMEA supports the identification of failure modes, failure effects, and risk priorities through severity, occurrence, and detection assessment [17], [18]. Nevertheless, previous applications often use these methods separately. The analytical link between reliability performance, downtime dominance, failure risk, root cause analysis, and RCM-based maintenance action is not always clearly explained. This creates a methodological gap because maintenance decisions should be based not only on failure frequency, but also on downtime contribution, risk level, process impact, and operational consequence.

Based on this gap, this study proposes an integrated RCM-based reliability decision framework for coating machine maintenance at PT. Triyasa Nagamas Farma. The coating machine was selected because its performance directly affects airflow stability, inlet temperature, spray distribution, drying quality, drum rotation, and process control. Failures in components such as the blower, spray gun/nozzle, coating drum, control panel, and exhaust fan can disturb coating uniformity and production continuity. Unlike previous studies that mainly apply RCM to general production machines, this study focuses on a pharmaceutical coating machine and integrates MTBF, MTTR, Availability, Pareto analysis, FMEA, RPN, Fishbone Diagram, and RCM decision logic into one structured maintenance priority framework. This study aims to analyze coating machine downtime, identify critical components and dominant failure modes, and formulate an RCM-based maintenance strategy to reduce downtime and improve machine reliability.

2. Methods

2.1 Research Design and Object

This study used a quantitative descriptive approach with a case study method to solve the downtime problem of the coating machine at PT. Triyasa Nagamas Farma. The study analyzed numerical data from actual machine operation, including downtime, failure frequency, operating time, repair time, and machine availability. The coating machine was selected because it directly affects coating uniformity, product quality, and production continuity in the pharmaceutical production process.

The components analyzed in this study were the blower, spray gun/nozzle, coating drum, control panel, and exhaust fan. These components were selected because they directly support the coating process and frequently contribute to machine downtime. The blower affects hot air circulation and drying stability, the spray gun/nozzle affects coating liquid distribution, the coating drum affects product movement and coating uniformity, the control panel regulates process parameters, and the exhaust fan supports air and moisture removal during the process.

2.2 Data Collection

The data used in this study consisted of primary and secondary data. Primary data were collected through direct observation and interviews with maintenance personnel. Direct observation was conducted to identify the actual condition of the coating machine, maintenance activities, operational problems, and failure events during the coating process. Interviews were conducted to obtain supporting information related to failure causes, repair actions, inspection practices, and maintenance problems that were not fully recorded in historical data.

Secondary data were obtained from company maintenance and production records. The secondary data included planned production time, setup and adjustment time, downtime, operating time, failure frequency, component breakdown data, repair time, and production output. Production output data were included to describe the operational achievement of the coating machine during the observation period and to support the interpretation of downtime effects on production performance. The observation period was conducted from March to April 2025.

2.3 Research Procedure

The research procedure was arranged as an integrated RCM-based reliability decision framework. The study began with problem identification, field observation, interview, and literature review. After the research objectives were determined, data were collected from production and maintenance records, including downtime data, failure frequency, operating time, repair time, and production output.

The collected data were then processed through several stages. First, downtime was recapitulated based on month and failed component. Second, reliability performance was calculated using MTBF, MTTR, and Availability. Third, Pareto analysis was used to identify dominant downtime contributors. Fourth, FMEA and RPN were used to determine failure risk priority. Fifth, Fishbone Diagram was used to identify root causes of the most critical component. Internal operational benchmarking between March and April 2025 was also used to compare downtime, MTBF, MTTR, and Availability. Finally, the RCM-based maintenance strategy was formulated based on downtime contribution, risk priority, root causes, and operational consequences. The research flow is presented in Figure 1.

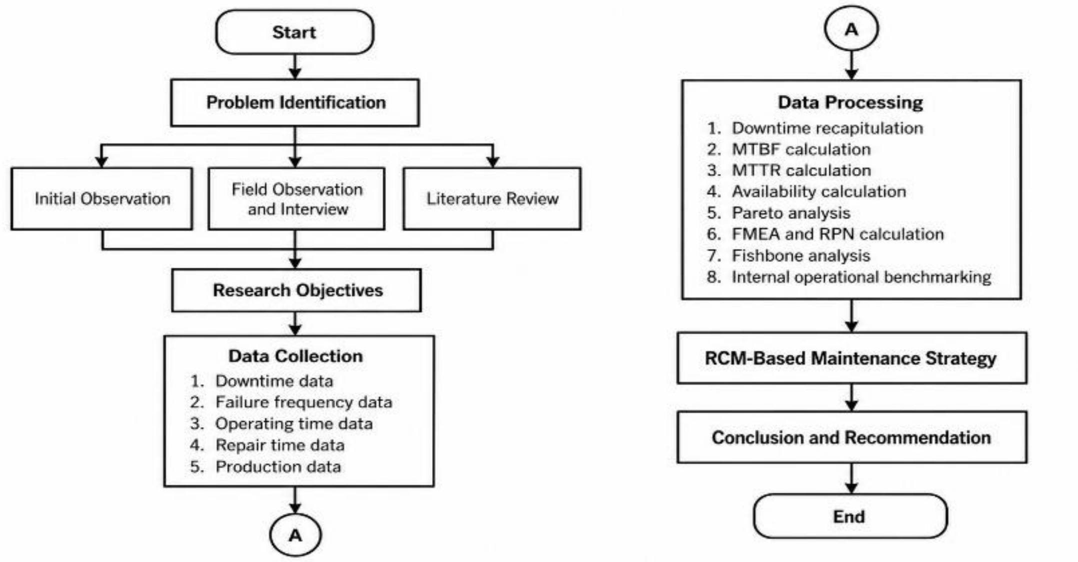

Figure 1. Research flowchart

Figure 1 shows that the study began with problem identification, followed by literature review, data collection, data classification, reliability calculation, Pareto analysis, FMEA and RPN calculation, Fishbone analysis, and RCM-based maintenance recommendation. This sequence was used so that each analysis stage produced input for the next stage.

2.4 Reliability Analysis

Reliability performance was evaluated using MTBF, MTTR, and Availability. MTBF was used to measure the average operating time between failures [19]. MTTR was used to measure the average repair time required to restore the machine after failure [20]. Availability was used to measure machine readiness during the production period [17]. The equations used in this study are shown in Equation (1), Equation (2), and Equation (3).

$$MTBF = \frac{Operating\ Time}{Number\ of\ Failures} \quad (1)$$

$$MTTR = \frac{Total\ Downtime}{Number\ of\ Failures} \quad (2)$$

$$Availability = \frac{Run\ Time}{Run\ Time + Unplanned\ Stop}\ X\ 100\% \quad (3)$$

where OT is operating time, DT is downtime failure, F is the number of failures, and A is Availability.

2.5 Pareto, FMEA, Fishbone, and RCM Strategy

Pareto analysis was used to identify components with the highest contribution to total downtime. This analysis ranked components based on downtime percentage and cumulative percentage so that maintenance resources could be focused on the most dominant contributors [3]. In this study, Pareto analysis was not used as a standalone descriptive tool, but as the first prioritization filter before risk assessment using FMEA.

FMEA was used to identify failure modes, potential causes, failure effects, and risk priority for each coating machine component [18]. The risk level was determined using Risk Priority Number (RPN), which was calculated from Severity, Occurrence, and Detection [2]. RPN was calculated using Equation (4).

$$RPN = Severity \times Occurrence \times Detection \quad (4)$$

where S is Severity, O is Occurrence, and D is Detection.

The final maintenance recommendation was developed using RCM decision logic. RCM was applied because it links equipment function, functional failure, failure mode, failure effect, and operational consequence to suitable maintenance tasks [5]. In this study, maintenance actions were classified into preventive maintenance and condition-based maintenance. Preventive maintenance was proposed for failure causes that could be controlled through scheduled cleaning, inspection, and calibration. Condition-based maintenance was proposed for failure causes that required periodic monitoring, such as airflow stability, inlet temperature, motor temperature, spray pressure, and suction performance [5], [16].

2.6 Internal Operational Benchmarking

Internal operational benchmarking was used to strengthen the validation of the maintenance priority results. The comparison was conducted between March and April 2025 using downtime, MTBF, MTTR, and Availability indicators. This comparison was not intended to represent a full post-implementation validation of the proposed RCM strategy. Instead, it was used as an internal operational benchmark to identify the direction of machine performance improvement and to evaluate whether lower downtime, longer failure interval, shorter repair time, and higher availability were realistic targets for the coating machine.

The benchmarking results were interpreted together with Pareto, FMEA, RPN, and Fishbone results. If a component had high downtime contribution, high RPN value, and root causes that could be controlled through inspection or monitoring, then the component was assigned a higher maintenance priority. This validation logic helped connect historical performance data with the proposed RCM-based maintenance strategy.

3.Results and Discussion

3.1 Production and Operational Data of Coating Machine

Downtime is an important operational issue because it reduces effective production time and affects production performance [1]. The first analysis was conducted by presenting the production and operational condition of the coating machine during the observation period. These data were used as the basis for evaluating downtime, reliability performance, and maintenance priority. The production and operational data included planned production time, setup and adjustment time, downtime, operating time, failure frequency, and production output. The production and operational data of the coating machine are presented in **Table 1**.

Table 1. Production and operational data of the coating machine

Month	Planned Production Time (min)	Setup and Adjustment (min)	Downtime (min)	Operating Time (min)	Failure Frequency	Production Output (pills)
March 2025	4,560	418	720	3,422	7	26,878
April 2025	6,420	525	390	5,505	5	32,308
Total	10,980	943	1,110	8,927	12	59,186

Source: Company production and maintenance records, processed by authors (2025).

Table 1 shows that the coating machine had a total planned production time of 10,980 minutes during the observation period. From this time, 943 minutes were used for setup and adjustment activities, while 1,110 minutes were lost due to machine downtime. Therefore, the total operating time of the coating machine was 8,927 minutes. During this period, the machine produced 59,186 pills and experienced 12 failure events.

The data also show that March 2025 had higher downtime than April 2025. In March, the machine experienced 720 minutes of downtime with 7 failure events and produced 26,878 pills. In April, downtime decreased to 390 minutes with 5 failure events, while production output increased to 32,308 pills. This condition indicates that downtime and failure frequency affected the available operating time and production output of the coating machine. This operational condition became the basis for calculating MTBF, MTTR, and Availability in the next analysis.

3.2 Reliability Performance Analysis

After the production and operational data were identified, reliability performance was analyzed using Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), and Availability. These indicators were used to evaluate machine reliability, repair performance, and readiness during the production period. MTBF represents the average operating time between failures, MTTR represents the average repair time after failure, and Availability represents the ability of the machine to remain ready for operation [17], [20] [21]. MTBF was calculated using Equation (1), MTTR was calculated using Equation (2), and Availability was calculated using Equation (3), as described in the Method section. The reliability performance of the coating machine is presented in **Table 2**.

Table 2. Reliability performance of the coating machine

Month	Operating Time (min)	Downtime (min)	Failure Frequency	MTBF (min/failure)	MTTR (min/failure)	Availability (%)
March 2025	3,422	720	7	488.86	102.86	82.62
April 2025	5,505	390	5	1,101.00	78.00	93.38
Total	8,927	1,110	12	743.92	92.50	88.94

Source: Authors' calculation based on company maintenance records (2025).

Table 2 shows that the coating machine had an MTBF of 743.92 minutes/failure, an MTTR of 92.50 minutes/failure, and an Availability of 88.94% during the observation period. The MTBF value indicates that, on average, the machine operated for 743.92 minutes before another failure occurred. The MTTR value indicates that the average repair time required to restore the machine after failure was 92.50 minutes. The Availability value indicates that the machine was available for production, but repeated failures still reduced its operational performance.

The reliability calculation also shows an improvement from March to April. MTBF increased from 488.86 minutes/failure in March to 1,101.00 minutes/failure in April, while MTTR decreased from 102.86 minutes/failure to 78.00 minutes/failure. Availability also increased from 82.62% to 93.38%. This improvement indicates that the machine condition in April was better than in March. However, the total downtime of 1,110 minutes still shows that a structured maintenance strategy is needed to reduce repeated failures.

$$MTBF = \frac{8{,}927}{12} = 743.92\ minutes/failure$$

$$MTTR = \frac{1{,}110}{12} = 92.50\ minutes/failure$$

$$Availability = \frac{743.92}{(743.92 + 92.50)} \times 100\% = 88.94\%$$

The comparison between March and April was used as an internal operational benchmark to evaluate the direction of machine performance improvement. Downtime decreased from 720 minutes in March to 390 minutes in April, representing a 45.83% reduction. MTBF increased from 488.86 minutes/failure to 1,101.00 minutes/failure, representing a 125.21% improvement in failure interval. MTTR decreased from 102.86 minutes/failure to 78.00 minutes/failure, representing a 24.17% reduction in repair time. Availability also increased from 82.62% to 93.38%, or by 10.76 percentage points. This comparison does not represent full post-implementation validation of the proposed RCM strategy. However, it provides an internal operational benchmark showing that lower downtime, longer failure interval, shorter repair time, and higher availability are realistic performance targets for the coating machine.

3.3 Downtime Contribution and Pareto Analysis

Pareto analysis is useful for identifying dominant problems so that improvement efforts can focus on the most influential downtime contributors [3]. After reliability performance was calculated, downtime was classified based on failed components. This classification was used to identify which components contributed most to total downtime. The downtime contribution of each component is presented in **Table 3**.

Table 3. Downtime contribution by component

Rank	Component	Failure Frequency	Downtime (min)	Percentage (%)	Cumulative (%)
1	Blower	5	390	35.14	35.14
2	Spray Gun/Nozzle	2	270	24.32	59.46
3	Coating Drum	2	240	21.62	81.08
4	Control Panel	2	150	13.51	94.59
5	Exhaust Fan	1	60	5.41	100.00
Total		12	1,110	100.00	

Source: Authors' processing based on downtime component data (2025).

Table 3 shows that the blower had the largest downtime contribution, with 390 minutes or 35.14% of total downtime. The second largest contributor was the spray gun/nozzle, with 270 minutes or 24.32%, followed by the coating drum, with 240 minutes or 21.62%. These three components contributed 900 minutes of downtime, equal to 81.08% of total downtime. This result shows that maintenance improvement should focus first on the blower, spray gun/nozzle, and coating drum.

The cumulative percentage of the three dominant components was calculated as follows:

$$Cumulative\ Percentage = \frac{(390 + 270 + 240)}{1{,}110} \times 100\% = 81.08\%$$

Table 3 was visualized using a Pareto diagram to strengthen the identification of dominant downtime contributors. The Pareto diagram of coating machine downtime components is presented in **Figure 2**.

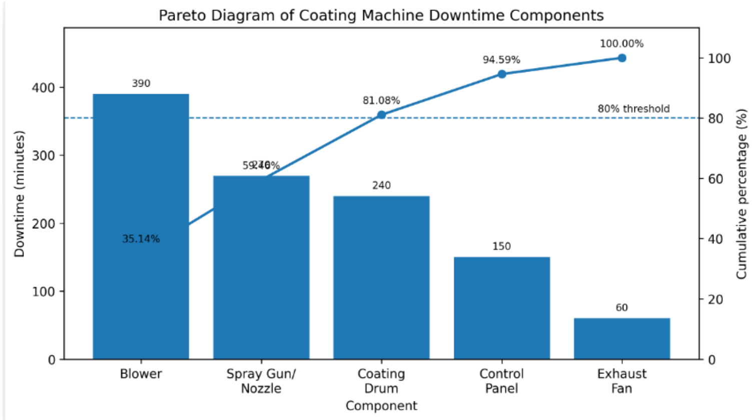

Figure 2. Pareto diagram of coating machine downtime components

Figure 2 confirms that the blower, spray gun/nozzle, and coating drum were the dominant contributors to coating machine downtime. The cumulative percentage reached 81.08%, which means that most downtime problems were concentrated in only three components. Therefore, maintenance actions should not be distributed equally to all components, but should be prioritized based on downtime contribution and process impact.

3.4 FMEA and Critical Component Analysis

Failure Mode and Effect Analysis (FMEA) was used to identify failure modes, failure effects, and risk priority for each component. The Risk Priority Number (RPN) value was calculated based on Severity, Occurrence, and Detection [18]. The FMEA results are presented in **Table 4**.

Table 4. FMEA and RPN results of coating machine components

Component	Failure Mode	Main Effect	S	O	D	RPN
Blower	Unstable airflow and inlet temperature	Drying process is disturbed and downtime occurs	8	8	6	384
Spray Gun/Nozzle	Blockage and uneven spraying	Uneven coating and defect risk increase	8	6	6	288
Control Panel	Setting error and panel restart	Process parameters become unstable	8	6	6	288
Coating Drum	Vibration and loose belt	Drum rotation becomes unstable	6	6	6	216
Exhaust Fan	Reduced suction performance	Humidity increases and drying quality decreases	6	3	6	108

Source: Authors' analysis based on observation, interview, and maintenance records (2025).

Table 4 shows that the blower had the highest RPN value of 384. This result indicates that blower failure had the highest risk level compared with other components. The blower also had the largest downtime contribution, with 390 minutes. Therefore, the blower was identified as the most critical component in the coating machine.

The spray gun/nozzle and control panel had the same RPN value of 288. However, the spray gun/nozzle was prioritized higher because it caused greater downtime and directly affected coating liquid distribution. Nozzle blockage can create an uneven spray pattern and increase the risk of product defects. The control panel also requires attention because it regulates important process parameters, such as temperature, spray time, pressure, and machine speed.

The coating drum had an RPN value of 216 and contributed 240 minutes of downtime. Although its RPN was lower than the blower, spray gun/nozzle, and control panel, the coating drum remained important because unstable drum rotation can affect coating uniformity. The exhaust fan had the lowest RPN value of 108 but still requires periodic inspection because reduced suction performance can increase humidity and disturb drying stability.

3.5 Root Cause Analysis of Blower Downtime

The root cause analysis was focused on the blower because it had the highest RPN value and the largest downtime contribution. The Fishbone Diagram was used to identify the causes of blower downtime based on man, machine, method, material, environment, and measurement factors [5]. The Fishbone Diagram of blower downtime causes is presented in **Figure 3**.

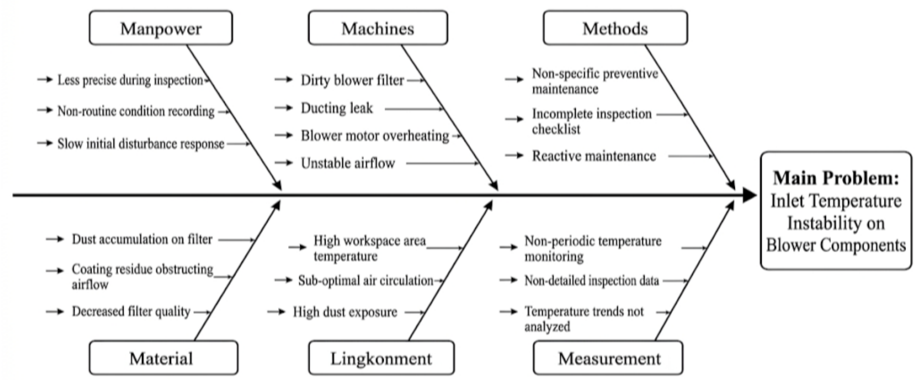

Figure 3. Fishbone diagram of blower downtime causes

Source: Authors' analysis based on observation and interview with maintenance personnel (2025).

Figure 3 shows that blower downtime was caused by several related factors. From the machine factor, the main causes were dirty blower filter, ducting leakage, unstable airflow, and motor overheating. From the method factor, the causes were incomplete inspection checklist and preventive maintenance that was not yet specific to blower condition. From the man factor, delayed response to temperature changes and inconsistent inspection discipline contributed to failure risk. From the material factor, dust accumulation and coating residue on the airflow path disturbed air circulation. From the environment factor, dust exposure and air circulation conditions affected blower performance. From the measurement factor, inlet temperature and airflow trends were not monitored periodically.

These causes indicate that blower downtime was not only related to component damage, but also to inspection method, maintenance discipline, and condition monitoring. Therefore, the proposed improvement should focus on routine inlet temperature inspection, airflow checking, periodic filter cleaning, motor temperature monitoring, ducting leakage inspection, and maintenance checklist recording.

3.6 Proposed RCM-Based Maintenance Strategy and Discussion

Based on the reliability calculation, Pareto analysis, FMEA, RPN ranking, and Fishbone analysis, an RCM-based maintenance strategy was developed for the coating machine. The strategy focused on the most critical components and the most relevant maintenance actions. The proposed maintenance strategy is presented in **Table 5**.

Table 5. Proposed RCM-based maintenance strategy

Component	Priority	Maintenance Action	Recommended Interval
Blower	1	Clean filter, check airflow, monitor motor temperature, inspect ducting, and record inlet temperature	Daily check, weekly cleaning, monthly inspection
Spray Gun/Nozzle	2	Clean nozzle, check spray pattern, inspect spray pressure, and remove coating residue	After production and weekly inspection
Control Panel	3	Check electrical connection, inspect error indicator, clean panel, and calibrate parameters	Weekly inspection and periodic calibration
Coating Drum	4	Check drum rotation, belt tension, bearing condition, and drum cleanliness	Weekly and monthly inspection
Exhaust Fan	5	Clean fan, inspect exhaust channel, and check suction performance	Weekly cleaning and monthly inspection

Source: Authors’ recommendation based on reliability, Pareto, FMEA, and Fishbone analysis (2025).

Table 5 shows that the blower became the first maintenance priority because it had the highest RPN and the largest downtime contribution. The recommended actions for the blower combine preventive maintenance and condition-based maintenance. Preventive actions include filter cleaning and ducting inspection, while condition-based actions include airflow checking, inlet temperature recording, and motor temperature monitoring.

The spray gun/nozzle became the second priority because it directly affects coating liquid distribution and contributed 270 minutes of downtime. Cleaning after production and spray pattern inspection are important to prevent blockage and uneven spraying. The control panel became the third priority because unstable control parameters can disturb the coating process. Therefore, electrical inspection, panel cleaning, and calibration are required. The coating drum and exhaust fan also require periodic inspection because both components affect product movement, drying stability, humidity control, and coating uniformity.

The findings indicate that maintenance priority should not be determined only by failure frequency. A component with high failure frequency does not always produce the highest operational impact if the downtime duration, failure effect, and detection difficulty are low. Therefore, this study combines downtime contribution, RPN value, process impact, and root cause analysis to determine maintenance priority. This logic is consistent with the RCM concept, where maintenance actions are selected based on equipment function, failure mode, failure effect, and operational consequence [2], [4]. In this case, the blower became the priority because it had the highest downtime contribution, the highest RPN value, and a direct effect on airflow stability and inlet temperature.

The blower failure also shows a causal relationship between component condition and coating process performance. Dirty filters, ducting leakage, unstable airflow, and motor overheating can reduce hot air circulation. This condition disturbs drying stability and may affect coating uniformity. Therefore, blower maintenance should not only focus on corrective repair after failure, but also on condition-based inspection, airflow monitoring, inlet temperature recording, and motor temperature monitoring. The spray gun/nozzle was placed as the second priority because blockage and uneven spraying directly affect coating liquid distribution. The coating drum, control panel, and exhaust fan also require periodic inspection because they influence drum rotation, parameter stability, humidity removal, and drying quality.

Compared with Total Productive Maintenance (TPM), the proposed RCM-based strategy is more suitable for this study because the main problem is related to critical component prioritization and failure consequence analysis. TPM is useful for improving operator involvement, autonomous maintenance, and maintenance culture, but it does not directly rank components based on downtime contribution and risk priority. Predictive maintenance can provide stronger failure prediction through sensor data and machine learning models, but it requires sufficient historical data, sensor infrastructure, and digital monitoring systems [6], [7]. Since the available data in this study were limited to downtime, failure frequency, repair time, and maintenance records, the integrated RCM-based framework was more practical as an initial reliability improvement strategy.

The proposed strategy can also serve as a transition stage toward condition-based and predictive maintenance. The recommended actions, such as airflow inspection, inlet temperature recording, motor temperature monitoring, spray pressure checking, and suction performance inspection, create structured condition data for future maintenance development [5]. Therefore, the contribution of this study is not only the identification of critical components, but also the formulation of a reliability-based maintenance priority framework for pharmaceutical coating machine operations. This framework helps maintenance teams focus resources on components with the highest downtime contribution, risk level, and operational consequence.

4. Conclusion

This study developed an integrated RCM-based reliability decision framework to formulate maintenance priorities for the coating machine at PT. Triyasa Nagamas Farma. The results showed that the machine experienced 12 failure events with a total downtime of 1,110 minutes, an MTBF of 743.92 minutes/failure, an MTTR of 92.50 minutes/failure, and an Availability of 88.94%. Pareto analysis showed that the blower, spray gun/nozzle, and coating drum contributed 81.08% of total downtime. FMEA identified the blower as the most critical component, with the highest RPN value of 384 and the largest downtime contribution of 390 minutes.

The main contribution of this study is the integration of reliability measurement, downtime dominance analysis, failure risk assessment, root cause analysis, internal operational benchmarking, and RCM decision logic into one structured maintenance priority framework. This framework shows that maintenance priority should not be determined only by failure frequency, but also by downtime contribution, process impact, risk level, root causes, and operational consequences. The proposed maintenance strategy emphasizes preventive and condition-based maintenance, including filter cleaning, airflow inspection, motor temperature monitoring, ducting inspection, nozzle cleaning, spray pattern checking, control panel calibration, and coating drum inspection.

This study has several limitations. The analysis was based on a two-month observation period and focused on one coating machine in one pharmaceutical company. The study also did not include probabilistic reliability modelling, uncertainty analysis, sensor-based monitoring, or full post-implementation validation. Future research should evaluate the proposed strategy through a longer before-after implementation study and compare RCM with TPM, condition-based maintenance, and predictive maintenance. Further studies can also apply Weibull reliability analysis, RPN sensitivity analysis, and sensor-based predictive models to improve maintenance decision accuracy.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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