

A Maintenance Strategy for Dosing Pumps Using Reliability-Centered Maintenance (RCM) and Spare Parts Ordering to Improve the Reliability of the Clean Water Supply System at PT. Dain Celicani Cemerlang

Johannes Kevin Purba ^{1✉}, Aulia Ishak ², Nurhayati ³

(1,2,3) Magister Teknik Industri Fakultas Teknik, Universitas Sumatera Utara, Medan, Indonesia

Abstract: The continuity of the clean water distribution process at PT Dain Celicani Cemerlang is highly dependent on the reliability of the dosing pumps. However, the maintenance system currently in place is still reactive (corrective maintenance), resulting in high operational downtime and uncontrolled maintenance costs. This study aims to improve the reliability of the clean water supply system by designing a maintenance strategy based on Reliability-Centered Maintenance (RCM) and optimizing spare parts management through a spare parts ordering system. The research method used is descriptive quantitative analysis, which involves analyzing reliability parameters such as Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), and Risk Priority Number (RPN) through a Failure Mode and Effect Analysis (FMEA) approach. In addition, the Economic Order Quantity (EOQ) and Period Order Quantity (POQ) methods were used to determine the most efficient spare parts ordering policy. The research results show that the implementation of appropriate RCM strategies (such as preventive maintenance and scheduled replacement) can significantly reduce system downtime by 89.21% and increase machine availability from 96.73% to 99.65%. From a cost perspective, implementing RCM yields savings of 24.27%, while integrating the EOQ and POQ methods into spare parts management reduces inventory costs by up to 41.73% compared to the company's current system. In conclusion, the integration of RCM with a structured spare parts ordering system is highly effective in ensuring the company's operational stability and cost efficiency.

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INTRODUCTION

In the era of industrialization and Industry 4.0, machines have become essential to manufacturing operations by driving production efficiency, maintaining product quality, and strengthening global competitiveness. Machine reliability plays a critical role in ensuring uninterrupted production, as equipment failures can cause production delays, increase operational costs, and reduce overall productivity. Consequently, improving machine reliability through the adoption of advanced technologies and effective maintenance strategies has become a key priority for manufacturing companies seeking to enhance operational performance (Singh & Tewari, 2023; Raharja et al., 2021).

Machine reliability refers to the ability of equipment to perform its intended function without failure over a specified period. It is determined by factors such as machine design, material quality, operating conditions, and maintenance practices. An effective maintenance system minimizes downtime, lowers maintenance costs, extends equipment service life, and improves operational

efficiency, whereas inadequate maintenance increases failure frequency and repair expenses. Therefore, ensuring high machine reliability through effective maintenance is essential for achieving sustainable operational performance in manufacturing industries (Rojek et al., 2023; Hamasha et al., 2023).

At PT Dain Celicani Cemerlang, the reliability of dosing pump machines is essential for ensuring the efficiency of clean water treatment and distribution processes. The company operates four dosing pump units to inject chemicals, including PAC, soda ash, and chlorine, during the coagulation and flocculation stages to maintain water quality. However, these pumps are susceptible to hydraulic, mechanical, electrical, and operational failures, such as cavitation, valve leakage, pipeline blockage, diaphragm damage, and incorrect stroke settings. Such failures can lead to inaccurate chemical dosing, reduce treatment effectiveness, increase operating costs, and disrupt the continuity of clean water supply. Therefore, implementing an effective maintenance strategy is critical to improving operational stability, enhancing efficiency, and minimizing equipment downtime.

Data frequency failure on Milton Roy GM0120PP1MNN dosing pump components in PT. Dain Celicani Brilliant Which recorded from month August 2023 until January 2025 is shown in Table 1.1.

Table 1.1. Frequency Damage Dosing Pump Machine in PT. Dain Celicani Brilliant (January 2024–October 2025).

No	Component	Spare Parts Involved	Frequency Damage (time)	Downtime (O'clock)	Total Downtime (O'clock)
1	Dosing Pump Not Turning On	Pump Motor, Power Cable	6	4	24
2	Clogged Foot Valve	Foot Valve, Seal	2	1	2
3	Burnt Power Cable	Power Cable, Relay	5	3	15
4	Dosing Pipe Leak	Dosing Pipe, Seal, Clamp	7	2	14
5	Bearing Damage	Bearing, Shaft	4	8	32
6	Gearbox Damage	Gearbox, Shaft, Oil Seal	4	12	48
7	Impeller Damage	Impeller, Shaft, O-Ring	6	4	24
8	Pump Motor Damage	Pump Motor, Seal, Bearing	10	24	240
9	Control Panel Damage	Relay, PCB, Fuse	6	4	24
10	Starter Relay Failure	Relay, Fuse	8	2	16
11	Broken Shaft	Shaft, Bearing	3	48	144
12	Clogged Suction Pipe	Suction Pipe, Filter	5	0.75	3.75
13	Leaking Pump Seal	Seal Pump	4	5	20
14	Sensor Level Error	Level Sensor, PCB	7	1	7
15	Dirty Strainer	Strainer, Filter	7	0.5	3.5

Source : PT. Dain Celicani Brilliant

Table 1.1 presents the frequency of dosing pump component failures from January 2024 to October 2025, highlighting variations in failure occurrences among components. The pump motor experienced the highest failure frequency, with 10 failures resulting in 240 hours of downtime (38.88%). This was followed by starter relay failures (8), dosing pipe leaks, level sensor errors, and dirty strainers (7 each), while impeller failures occurred 6 times. Although shaft failures were recorded only 3 times, they contributed 144 hours of downtime (23.33%), indicating their significant operational impact. These findings suggest that the current maintenance system has not been sufficiently effective in preventing failures of critical components. Therefore, pump motors, shafts, starter relays, impellers, dosing pipes, and foot valves should be prioritized in maintenance planning because their failures directly increase downtime, reduce equipment reliability, and disrupt the continuity of the clean water supply system at PT Dain Celicani Cemerlang.

Effective implementation of Reliability-Centered Maintenance (RCM) should be complemented by an efficient spare parts management system to ensure timely component availability. One widely used approach is the Economic Order Quantity (EOQ) method, which optimizes inventory by determining the appropriate order quantity and timing. Integrating RCM with EOQ enables the company to estimate replacement requirements more accurately, reducing the risk of maintenance delays caused by spare parts shortages. Consequently, this integrated approach can improve dosing pump maintenance effectiveness, minimize downtime, optimize maintenance costs, and enhance the long-term reliability of the clean water supply system at PT Dain Celicani Cemerlang.

Based on the established research questions, the research questions are:

1. To determine a Reliability-Centered Maintenance (RCM)-based maintenance strategy for dosing pumps through the identification of critical components, failure modes, and optimal maintenance actions to improve the reliability of the clean water supply system at PT. Dain Celicani Cemerlang.
2. To determine a spare parts ordering policy, optimal maintenance intervals, and estimated maintenance costs for dosing pumps to support improved reliability of the clean water supply system at PT. Dain Celicani Cemerlang.

RESEARCH METHOD

Types and Approaches of Research

This study employs an applied quantitative approach supported by descriptive analysis to improve the reliability of dosing pump machines at PT Dain Celicani Cemerlang through the implementation of Reliability-Centered Maintenance (RCM) and the development of a spare parts ordering system. Reliability indicators, including failure frequency, Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and component failure probability, are analyzed to identify appropriate maintenance strategies based on RCM principles. The analysis results are subsequently used to establish an efficient spare parts ordering policy that ensures component availability while minimizing operational disruptions. Ultimately, the proposed approach is expected to provide practical recommendations for enhancing maintenance effectiveness and optimizing spare parts management within the company.

Location and Time of Research

This research was conducted from August 2025 to November 2025 at PT Dain Celicani Cemerlang, located in the Medan industrial area, North Sumatra Province. The research focused on the reliability of dosing operations. pump and maintenance and spare part policy design Ordering applied to the pump system.

Research Object

dosing pump machine system. pump and spare part ordering system used in the process of providing and distributing clean water at PT Dain Celicani Cemerlang, which has a very important role in maintaining operational continuity but still faces a decline in performance due to component reliability that has not been analyzed systematically. Through the application of the Reliability Centered Maintenance (RCM) method, this system is studied to determine the level of reliability, frequency of failure, and the effectiveness of the maintenance strategy applied, while also by implementing a spare part ordering system to assess the efficiency of procurement and storage of spare parts in supporting machine performance.

Data and Data Sources

The study utilizes both primary and secondary data to support the implementation of Reliability-Centered Maintenance (RCM) and the design of a spare parts ordering system at PT Dain Celicani Cemerlang. Primary data were collected through direct observations, interviews with technicians, operators, maintenance supervisors, and spare parts warehouse staff, as well as operational records documenting failure frequency, Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), failure types and causes, and current maintenance practices. Secondary data were obtained from company documents, including maintenance histories, maintenance schedules, spare parts inventory and ordering records, operation manuals, machine specifications, and relevant literature on machine reliability, RCM, and spare parts management.

Data Collection Techniques

Technique collection data in study This done in a way systematic For get information Which accurate, relevant, And can accountable. Objective main from process collection data is get description comprehensive about condition current reliability machine pump, system maintenance Which applied, as well as policy management ethnic group spare parts in PT. Dain Celicani Brilliant.

1. Observation Direct

Observation done in a way direct in location operational machine pump For get data empirical about condition equipment, frequency damage, And process maintenance Which done by team technician. Through observation This, researchers can observe pattern Work machine, identify symptom beginning failure, as well as take notes data about time damage And time repair. Observation Also used For evaluate effectiveness activity maintenance preventive And predictive Which has implemented company.

2. Interview

Interview done with parties Which own involvement direct in activity operational And maintenance machine. Respondents main covering technician maintenance, operator machine pump, supervisor maintenance department, as well as staff logistics Which handle storage And

booking ethnic group spare parts. Question in interview It is hoped that it can provide a general overview of the performance of the dosing machine. pump, and the spare parts fulfillment process with the hope that the data obtained is company history data for analysis.

3. Studies Literature

Besides data field, researchers Also do studies literature For get runway theoretical Which strong in analysis. Studies literature covers search journal scientific, book, report study, And source academic other Which relevant with Reliability Centered Maintenance (RCM) topic, analysis reliability, as well as Sparepart Ordering Management . Through studies literature, researchers get understanding deep about principles RCM, method calculation parameter reliability, as well as implementation draft the in field industry similar.

Through combination various technique collection data the, study This make an effort ensure that all over information Which obtained reflect condition current in field as well as support process analysis Which accurate. Approach triangulation data used For verify consistency between data observation, interview, And literature, so that results study own validity And reliability Which tall.

RESULTS AND DISCUSSION

Data Collection

Data collection for this research was obtained from operational data and historical data on dosing pump machine failures at PT Dain Celicani Cemerlang. The data were collected during the observation period of August 2023 - January 2025. The data used were quantitative and included key information related to failure events, such as failure frequency, downtime duration per event, and total downtime incurred by each component. This data served as the basis for conducting a system reliability analysis.

In addition, researchers also collected informative data regarding the components and spare parts involved in each failure event, as well as inventory data such as annual requirements, lead times, and spare part storage policies as implemented by the company. The data was used to support machine reliability analysis activities using the Reliability Centered Maintenance (RCM) approach and the design of an optimal spare part ordering system.

The data structure is structured based on the failure events identified for each component, enabling researchers to analyze component criticality levels, failure patterns, and the contribution of downtime to overall system performance. More specifically, the processed data used in this study is presented in Table 4.1.

Table 4.1 Component Damage Incident Data

No	Component	Frequency of Damage (times)	Total Downtime (hours)
1	Power Cable	8	132
2	Seal Bearing	5	120
3	Shaft	4	48
4	Bearing	3	32
5	Gearbox	2	24
6	Shaft Oil Seal	2	24
7	Relay	8	22
8	Seal Pump	4	20

9	<i>Fuse</i>	6	16
10	<i>Pump Motor</i>	3	12
11	<i>Impeller</i>	3	12
12	<i>PCB / Control Panel</i>	6	12
13	<i>Shaft Oil Ring</i>	3	12
14	<i>Motor Cable</i>	3	9
15	<i>Dosing Pipe</i>	4	8
16	<i>Filter</i>	6	6
17	<i>Seal Clamp</i>	3	6
18	<i>Level Sensor</i>	4	4
19	<i>Strainer</i>	3	3
20	<i>Suction Pipe</i>	2	2
21	<i>Foot Valve</i>	1	1
22	<i>Seal Valve</i>	1	1
Total		84	526

Source: PT Dain Celicani Cemerlang, 2026

Based on Table 4.1 above, the downtime percentage is then calculated to determine the contribution of each component to the total system downtime . The results of this calculation are used to identify critical components that have the most significant impact on operational disruptions. The downtime percentage formula is as follows:

$$\text{Persentase Downtime (\%)} = \frac{\text{Total downtime komponen}}{\text{Total downtime seluruh komponen}} \times 100\%$$

This also applies to all components, where the results are more clearly shown in Table 4.2.

Table 4.2 Percentage of Component Downtime

No	Component	Downtime Percentage (%)
1	Power Cable	25.10
2	Seal Bearing	22.81
3	Shaft	9.13
4	Bearing	6.08
5	Gearbox	4.56
6	Shaft Oil Seal	4.56
7	Relay	4.18
8	Seal Pump	3.80
9	Fuse	3.04
10	Pump Motor	2.28
11	Impeller	2.28
12	PCB / Control Panel	2.28
13	Shaft Oil Ring	2.28
14	Motor Cable	1.71
15	Dosing Pipe	1.52
16	Filter	1.14
17	Seal Clamp	1.14
18	Level Sensor	0.76

19	Strainer	0.57
20	Suction Pipe	0.38
21	Foot Valve	0.19
22	Seal Valve	0.19
Total		100

Source: PT Dain Celicani Cemerlang, 2026

The same applies to other components. More detailed MTBF, MTTR, and availability results are shown in Table 4.3.

Table 4.3 MTBF, MTTR, and Component Availability

No	Component	Frequency of Damage	Total Downtime (hours)	MTBF (hours)	MTTR (hours)	Availability (%)
1	Power Cable	8	132	2,010	16.5	99.19
2	Seal Bearing	5	120	3,216	24	99.26
3	Shaft	4	48	4,020	12	99.70
4	Bearing	3	32	5,360	10.67	99.80
5	Gearbox	2	24	8,040	12	99.85
6	Shaft Oil Seal	2	24	8,040	12	99.85
7	Relay	8	22	2,010	2.75	99.86
8	Seal Pump	4	20	4,020	5	99.88
9	Fuse	6	16	2,680	2.67	99.90
10	Pump Motor	3	12	5,360	4	99.93
11	Impeller	3	12	5,360	4	99.93
12	PCB / Control Panel	6	12	2,680	2	99.93
13	Shaft Oil Ring	3	12	5,360	4	99.93
14	Motor Cable	3	9	5,360	3	99.94
15	Dosing Pipe	4	8	4,020	2	99.95
16	Filter	6	6	2,680	1	99.96
17	Seal Clamp	3	6	5,360	2	99.96
18	Level Sensor	4	4	4,020	1	99.98
19	Strainer	3	3	5,360	1	99.98
20	Suction Pipe	2	2	8,040	1	99.99
21	Foot Valve	1	1	16,080	1	99.99
22	Seal Valve	1	1	16,080	1	99.99

Source: PT. Dain Celicani Cemerlang, 2026

Under actual conditions, the probability of a dosing pump operating without failure for 7 days is only about 40.36%. This indicates that the system is still predominantly corrective maintenance, rather than controlled preventive maintenance.

In addition to component reliability data, researchers also present spare part inventory data used to support dosing pump maintenance activities. This inventory data aims to provide an overview of spare part demand patterns, company storage policies, and the lead time for each component. This information is considered crucial because spare part availability directly influences the smoothness of the repair process and the duration of downtime.

Inventory data is organized based on order frequency and the amount of stock held by the company. This data is presented in Table 4.4 below:

Table 4.4 Inventory Data

No.	Part Name	Order Frequency	Stock Amount
1.	Power Cable	5 times	0 units
2.	Seal Bearing	5 times	0 units
3.	Shaft	2 times	1 unit
4.	Bearing	1 time	1 unit
5.	Gearbox	2 times	0 units
6.	Shaft Oil Seal	2 times	0 units
7.	Relay	0 times	2 units
8.	Fuse	0 times	1 unit
9.	Filter	0 times	2 units
10.	Dosing Pipe	0 times	2 units
11.	Seal Clamp	0 times	1 unit
12.	Level Sensor	0 times	1 unit
13.	Strainer	0 times	1 unit
14.	Suction Pipe	0 times	1 unit
15.	Foot Valve	0 times	2 units
16.	Seal Valve	0 times	1 unit
17.	Seal Pump	0 times	1 unit
18.	Motor Cable	0 times	1 unit
19.	Shaft Oil Ring	0 times	1 unit
20.	Impeller	0 times	1 unit
21.	PCB / Control Panel	0 times	0 units
22.	Pump Motor	0 times	0 units

Source: PT. Dain Celicani Cemerlang, 2026

According to Table 4.4, it can be traced that each component has a different inventory condition and ordering frequency according to the level of need and the level of damage to the dosing pump system. Some components such as Power Cables and Seal Bearings have the highest ordering frequency, namely 5 times each, but do not have spare stock in the warehouse. This condition indicates that these two components are critical components with a high level of use, so the company tends to make direct purchases when damage occurs.

Other components such as Shaft, Bearing, Gearbox, and Shaft Oil Seal also still require reordering even though some have limited reserve stock. This shows that the level of need for main mechanical components is still quite high and has the potential to cause repair delays if procurement is not carried out in a timely manner. In addition, several components such as Relay, Fuse, Filter, Dosing Pipe, Foot Valve, and Seal Pump already have reserve stock in the warehouse so that during the research period no additional orders were made. The provision of this stock aims to anticipate sudden damage and reduce the risk of downtime due to delays in spare part procurement.

However, there were still critical components, such as PCBs/Control Panels and Pump Motors, that were not in stock or ordered frequently during the study period. This situation indicates that the company has not fully implemented an optimal inventory control system for all critical components. If these components suddenly fail, the potential for downtime could increase as the company must wait for procurement from suppliers.

Analysis of Actual Condition of Maintenance System

At this stage, a further analysis was conducted on the actual condition of the dosing pump maintenance system operated by PT Dain Celicani Cemerlang. This analysis was intended to evaluate the effectiveness of the current maintenance system, in line with the reliability data obtained, such as damage frequency, downtime, MTBF, MTTR, and the availability level of each component.

Downtime Percentage Analysis

This analysis was conducted to determine how each component contributes to downtime in the dosing pump system at PT Dain Celicani Cemerlang. This downtime percentage represents the extent to which a component impacts overall system performance. It should be noted that the higher the downtime percentage for a component, the greater its impact on operational efficiency.

Based on the results of data processing in Table 4.1 and Table 4.2, it is known that the total system downtime during the observation period was 526 hours. Of the total downtime, the power cable component was the largest contributor to downtime with a total of 132 hours or 25.10% of the total system downtime. The high contribution of downtime to this component indicates that the power cable is one of the critical components that greatly affects the continuity of dosing pump operations. In addition to having a high frequency of damage, namely 8 times, the repair and replacement process of components also requires a relatively long time, causing a large accumulation of downtime.

The next critical component is the bearing seal, with a total downtime of 120 hours, or 22.81%. Although its failure frequency is lower than that of the Power Cable, at 5 times, the relatively high average repair time makes this component contribute significantly to the system's downtime. This indicates that bearing seal damage has a significant impact on operational continuity and requires special attention in maintenance planning.

Furthermore, the shaft component also significantly impacted the system, with a total downtime of 48 hours, or 9.13%. Shaft failure is classified as a high-impact failure, as despite the frequency of failure being only four times, the repair time is relatively long, resulting in significant operational downtime. This indicates that failure of the main mechanical component has a significant impact on the reliability of the dosing pump system.

Other components such as bearings, gearboxes, and shaft oil seals are also included in the critical component category because they contribute significantly to downtime, at 6.08%, 4.56%, and 4.56%, respectively. Damage to these components directly affects the main mechanical system, potentially reducing operational performance if not addressed quickly and appropriately.

On the other hand, several components contributed relatively little to downtime, such as foot valves, suction pipes, and valve seals, each with a downtime percentage below 1%. Although some of these components did experience damage during the observation period, their repair times were relatively short, so their impact on total system downtime was not significant.

Critical Component Ranking Analysis (Pareto)

A Pareto analysis was performed to identify critical components that contributed the most to the total downtime of the dosing pump system at PT. Dain Celicani Cemerlang. The Pareto principle (80/20) indicates that most problems in a system are generally caused by a small number of primary factors (Amri & Nurjaya, 2022). Through this analysis, improvement priorities can be determined by focusing attention on the components that most influence system performance.

The data used in the Pareto Analysis is characterized as the result of processing the total downtime of each component, which is then sorted from the largest to the smallest value, as well as completed with the calculation of the percentage contribution and cumulative. The results of the data processing are presented in Table 4.5 below:

Table 4.5 Pareto Analysis of Component Downtime

No.	Component	Total Downtime (Hours)	Percentage (%)	Cumulative (%)
1.	Power Cable	132	25.10	25.10
2.	Seal Bearing	120	22.81	47.91
3.	Shaft	48	9.13	57.04
4.	Bearing	32	6.08	63.12
5.	Gearbox	24	4.56	67.68
6.	Shaft Oil Seal	24	4.56	72.24
7.	Relay	22	4.18	76.42
8.	Seal Pump	20	3.80	80.22
9.	Fuse	16	3.04	83.26
10.	Pump Motor	12	2.28	85.54
11.	Impeller	12	2.28	87.82
12.	PCB / Control Panel	12	2.28	90.10
13.	Shaft Oil Ring	12	2.28	92.38
14.	Motor Cable	9	1.71	94.09
15.	Dosing Pipe	8	1.52	95.61
16.	Filter	6	1.14	96.75
17.	Seal Clamp	6	1.14	97.89
18.	Level Sensor	4	0.76	98.65
19.	Strainer	3	0.57	99.22
20.	Suction Pipe	2	0.38	99.60
21.	Foot Valve	1	0.19	99.79
22.	Seal Valve	1	0.19	100.00

Source: PT. Dain Celicani Cemerlang, 2026

Based on Table 4.5, it can be interpreted that there are 6 components that contribute the most downtime, including the power cable, bearing seal, shaft, bearing, gearbox, and shaft oil seal. The total downtime of these six components is calculated as follows:

$$132 + 120 + 48 + 32 + 24 + 24 = 380 \text{ hours}$$

Considering that the total downtime of all components is 526 hours, the percentage contribution of the cumulative downtime of the six components is:

$$\frac{380}{526} \times 100\% = 72.24\%$$

These results show that just six types of spare parts accounted for 72.24% of the system's total actual downtime. This indicates that most operational disruptions were concentrated in a small number of highly critical components.

To clarify, the researcher also displays a Pareto graph visualization in Figure 4.1 as follows:

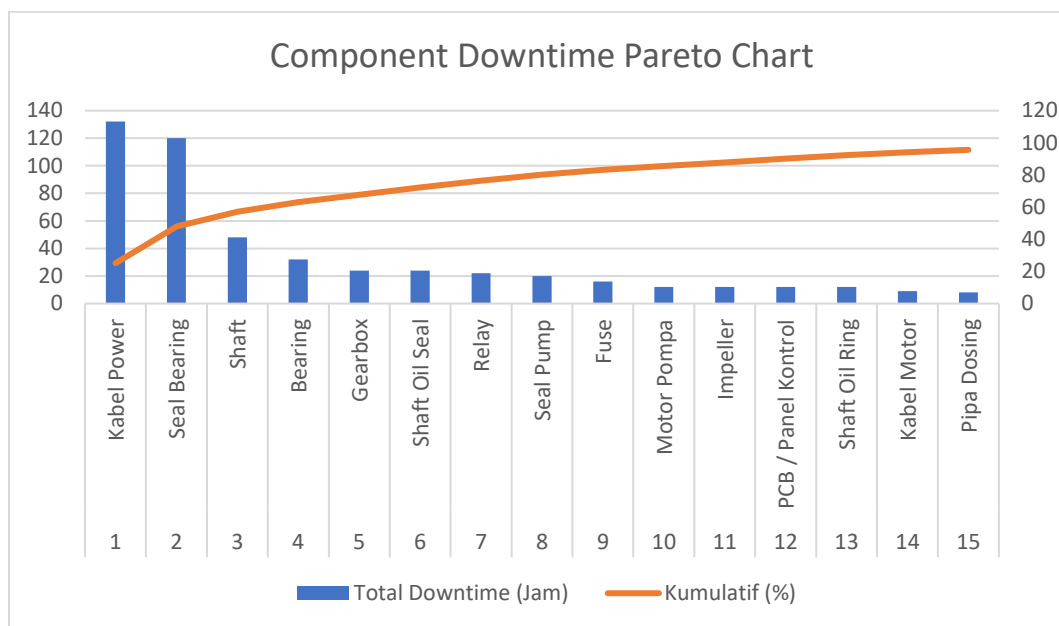


Figure 4.1 Pareto Chart of Component Downtime

Source: Microsoft Excel Output, 2026

Based on Figure 4.1, it is reflected that the cumulative curve experienced a relatively significant increase in several initial components, especially the power cable and bearing seal. After passing through these components, the curve began to indicate a downward trend. This means that the additional contribution from subsequent components to the total downtime is relatively small. The cumulative point approaching 80% can be reached in 6 main components, namely the power cable, bearing seal, shaft, bearing, gearbox, and shaft oil seal. This further strengthens the argument that the Pareto principle truly applies to this system, where the majority of downtime problems are caused by a small number of critical components.

In addition, the dominance of downtime by these components also indicates that the failures that occur are not evenly distributed, but are focused on certain components that have a lower level of reliability or a greater impact on the system.

Initial Maintenance Cost Analysis

Maintenance cost analysis was conducted to determine the company's expenditures for handling component failures in the dosing pump system. Maintenance costs in this study include labor/operator costs for repairs and spare part procurement costs if components require replacement.

In this study, cost calculations were conducted using an adjustment approach to market prices for similar industrial components, given limited access to actual company cost data. Spare part price estimates were obtained by averaging the lowest and highest prices from several e-commerce platforms and industrial marketplaces, such as Tokopedia and Shopee, as well as price references for similar components. The researchers also present a breakdown of the average price of each component along with an estimated annual requirement, based on the frequency of damage identified during the study period.

However, not all component damage is directly handled through spare part replacement. In certain conditions, damage can still be handled through repair actions without component replacement. Therefore, this study distinguishes between repair costs and replacement costs. Repair costs are calculated based on the maintenance operator cost of Rp200,000 for each repair incident, which consists of two workers at a cost of Rp100,000 per person. Meanwhile, replacement costs are calculated based on the price of spare parts used if the component is considered uneconomical to repair or has a low level of reliability so that it is more effective to replace it with a new component.

So, seal bearing It is recommended to replace it , because the cost is cheaper than repair and the downtime is reduced significantly.

4.6 Maintenance Costs and Comparison of Repair - Replacement Strategies

Part	Frequency	Actual Downtime	Part Price	Repair Costs	99% Replacement Cost	Downtime Reduced	Decision
Power Cable	8	132 hours	Rp. 200,000	Rp1,600,000	Rp1,616,000	130.68 hours	Change
Seal Bearing	5	120 hours	Rp. 170,000	Rp1,000,000	Rp. 860,000	118.80 hours	Change
Shaft	4	48 hours	Rp. 400,000	Rp. 800,000	Rp1,608,000	47.52 hours	Change
Bearing	3	32 hours	Rp. 100,000	Rp. 600,000	Rp. 306,000	31.68 hours	Change
Shaft Oil Seal	2	24 hours	Rp. 70,000	Rp. 400,000	Rp. 144,000	23.76 hours	Change
Gearbox	2	24 hours	Rp2,500,000	Rp. 400,000	Rp5,004,000	23.76 hours	Repair / standby spare
Relay	8	22 hours	Rp. 120,000	Rp1,600,000	Rp976,000	21.78 hours	Change
Seal Pump	4	20 hours	Rp. 70,000	Rp. 800,000	Rp. 288,000	19.80 hours	Change
Fuse	6	16 hours	Rp. 629,000	Rp1,200,000	Rp3,780,000	15.84 hours	Periodic repair / inspection
Impeller	3	12 hours	Rp. 500,000	Rp. 600,000	Rp1,506,000	11.88 hours	Change
Pump Motor	3	12 hours	Rp. 19,000,000	Rp. 600,000	Rp. 57,006,000	11.88 hours	Repair
PCB / Control Panel	6	12 hours	Rp1,500,000	Rp1,200,000	Rp9,012,000	11.88 hours	Repair
Motor Cable	3	9 hours	Rp. 200,000	Rp. 600,000	Rp. 606,000	8.91 hours	Change
Dosing Pipe	4	8 hours	Rp. 150,000	Rp. 800,000	Rp. 608,000	7.92 hours	Change
Filter	6	6 hours	Rp1,250,000	Rp1,200,000	Rp. 7,500,000	5.94 hours	Cleaning / repair
Seal Clamp	3	6 hours	Rp. 50,000	Rp. 600,000	Rp. 156,000	5.94 hours	Change
Level Sensor	4	4 hours	Rp. 500,000	Rp. 800,000	Rp2,008,000	3.96 hours	Repair / calibration

Strainer	3	3 hours	Rp. 100,000	Rp. 600,000	Rp. 306,000	2.97 hours	Change
Suction Pipe	2	2 hours	Rp. 100,000	Rp. 400,000	Rp204,000	1.98 hours	Change
Foot Valve	1	1 hour	Rp. 120,000	Rp. 200,000	Rp. 122,000	0.99 hours	Change
Seal Valve	1	1 hour	Rp. 70,000	Rp. 200,000	Rp. 72,000	0.99 hours	Change

Source: Market Data, 2026

Based on Table 4.6, each dosing pump component exhibits different failure characteristics and economic considerations for maintenance. The analysis incorporates failure frequency, total downtime, operator labor costs of Rp200,000 per repair, spare part prices, and the reliability improvement achieved through component replacement, which increases reliability to nearly 99% while substantially reducing downtime. The results indicate that components such as power cables, bearing seals, bearings, relays, pump seals, dosing pipes, seal clamps, and strainers are more economically maintained through replacement because the replacement cost is lower than the cumulative cost of repeated repairs. For instance, the power cable experienced eight failures with 132 hours of downtime. Although repeated repairs cost Rp1,600,000, replacing the component significantly reduces downtime to approximately 130.68 hours while increasing reliability to nearly 99%. A similar trend was observed for the bearing seal, where the replacement cost of Rp860,000 was lower than the accumulated repair cost of Rp1,000,000, making replacement the more cost-effective strategy.

In contrast, components such as gearboxes, pump motors, PCBs/control panels, filters, and level sensors are more economically managed through repair combined with the availability of standby spare parts. This is primarily due to their high replacement costs relative to repair expenses. For example, replacing a pump motor costs approximately Rp57,006,000, far exceeding the repair cost of Rp600,000, making repair the preferred option when the component remains serviceable. Likewise, replacing a gearbox requires approximately Rp5,004,000 with 24 hours of downtime; therefore, repair supported by standby spare parts is recommended to avoid procurement delays. Similarly, filters, valued at Rp1.250.000 are more efficiently maintained through periodic cleaning and repair because their associated downtime is relatively low, making direct replacement economically unjustified.

In addition to repair and replacement expenses, the company incurs inventory costs comprising an ordering cost of Rp100,000 for each spare parts purchase and a monthly holding cost of Rp230,000 to maintain warehouse inventory. These holding costs cover storage, inventory handling, and the risk of component deterioration or excess stock. Inventory records indicate that critical components, including power cables, bearing seals, gearboxes, and PCBs/control panels, are not maintained as backup stock, requiring procurement whenever failures occur. Consequently, power cables and bearing seals each required five purchase orders during the observation period, while shaft and gearbox components also needed repeated orders because of their high criticality and long procurement lead times. In contrast, components such as relays, filters, dosing pipes, foot valves, and level sensors were readily available in warehouse inventory, eliminating the need for additional orders during the study period. Maintaining these spare parts in stock helps minimize downtime by ensuring immediate component availability when unexpected failures occur in the dosing pump system at PT Dain Celicani Cemerlang.

The analysis of the existing maintenance system at PT Dain Celicani Cemerlang shows that spare parts inventory management and maintenance practices remain largely reactive and corrective. The company incurs a total annual inventory cost of IDR 4,260,000, consisting of ordering and holding costs, yet several critical spare parts are not stocked, resulting in repeated emergency purchases, longer repair times, and increased operational downtime. Reliability analysis using Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) identified power cables and relays as the most critical components due to their low MTBF and relatively high repair times, whereas foot valves and seal valves demonstrated the highest reliability with the longest MTBF values.

Further analysis of the actual maintenance schedule reveals that maintenance activities are performed only after failures occur, without preventive inspection or replacement intervals based on reliability indicators. Critical components such as power cables, seal bearings, relays, and shafts experience frequent failures and prolonged downtime because maintenance is not scheduled according to their MTBF values. The absence of a structured preventive maintenance program increases the likelihood of unexpected breakdowns, disrupts the continuity of dosing pump operations, and reduces overall system reliability and maintenance efficiency.

Overall, the findings indicate that the current maintenance strategy is inefficient and requires a transition from corrective maintenance to Reliability Centered Maintenance (RCM). Implementing an RCM-based maintenance system supported by reliability parameters, planned inspection intervals, and optimized spare parts inventory management would improve equipment reliability, reduce unexpected failures and downtime, enhance maintenance planning, and lower total operational and maintenance costs while ensuring more stable and efficient dosing pump performance.

Comparison of Actual Conditions and RCM

After providing maintenance suggestions, the researcher then compared the actual conditions and conditions after implementing the RCM strategy, in terms of comparing maintenance schedules, downtime, and maintenance costs.

The comparison between the current maintenance system and the Reliability Centered Maintenance (RCM) approach shows a significant improvement in maintenance planning and system performance. Under the current system, maintenance is purely corrective, with repairs performed only after failures occur, resulting in unpredictable breakdowns and frequent downtime, particularly for critical components such as power cables, relays, pump motors, and control panels. In contrast, the RCM approach establishes preventive maintenance intervals based on Mean Time Between Failure (MTBF) and Weibull reliability analysis with a minimum reliability target of 80%. Components with higher failure rates, such as power cables and relays, are scheduled for more frequent maintenance, while components with lower failure risks receive longer maintenance intervals.

The implementation of RCM also demonstrates substantial improvements in operational performance by significantly reducing downtime. Total system downtime decreases from 526 hours to 56.74 hours, representing an 89.21% reduction, as preventive maintenance allows potential failures to be identified and addressed before breakdowns occur. As a result, system availability increases from 96.73% to 99.65%, indicating a more reliable and stable operation. This proactive maintenance strategy minimizes unexpected failures and improves the overall efficiency of the dosing pump system.

From an economic perspective, RCM provides considerable cost savings compared to the existing corrective maintenance approach. Total maintenance costs decrease from IDR 16,800,000 to

IDR 12,723,000, achieving a 24.27% cost reduction through selective replacement of low-cost, high-failure components while maintaining repair strategies for more expensive items. In addition, the number of unplanned failures is significantly reduced, and the 7-day system reliability improves from 40.36% to 84.83%, demonstrating that the integrated RCM strategy enhances maintenance effectiveness, reduces operational losses, and improves the overall reliability and sustainability of the dosing pump system.

Spare Part Ordering Analysis

Spare parts ordering analysis was conducted to identify the most efficient inventory control strategy for the dosing pump system at PT Dain Celicani Cemerlang. The analysis aims to minimize total inventory costs, including ordering and holding costs, while ensuring spare parts availability to prevent downtime caused by delayed component replacement. To achieve this objective, the study applies two inventory control methods: Economic Order Quantity (EOQ) and Periodic Order Quantity (POQ).

The EOQ method was used to determine the optimal order quantity by balancing ordering and holding costs. The results indicate that most spare parts have an optimal order size of approximately one unit, suggesting that frequent, low-volume purchases are more cost-effective because of relatively high holding costs. The analysis also reveals inefficiencies in the current inventory system, where several critical components are unavailable despite their significant contribution to downtime. Implementing EOQ can therefore reduce inventory costs while improving the availability of essential spare parts.

The POQ method was subsequently applied to determine appropriate replenishment intervals based on demand patterns and EOQ results. Ordering intervals range from 2 to 12 months depending on annual demand. Critical, high-demand components, such as power cables, relays, fuses, filters, and PCB/control panels, require more frequent replenishment, whereas low-demand items, including foot valves and seal valves, can be ordered at longer intervals. The combined use of EOQ and POQ provides a more efficient and proactive inventory control strategy than the company's existing reactive ordering practice.

To further optimize inventory management, Material Requirements Planning (MRP) was used to develop a 12-month spare parts procurement schedule by integrating demand forecasts, EOQ values, POQ intervals, lead times, and current inventory levels. The MRP analysis indicates that purchase orders should be released before anticipated demand to maintain adequate stock and avoid shortages. Overall, integrating Reliability-Centered Maintenance (RCM) with EOQ, POQ, and MRP establishes a systematic maintenance and inventory management framework that reduces downtime, improves maintenance efficiency, ensures the availability of critical spare parts, and optimizes both inventory and operational costs.

Comparison of Inventory Methods

A comparison of inventory methods was conducted to evaluate the effectiveness of the company's current spare parts management policy compared to the EOQ and POQ approaches. This analysis aims to determine the most optimal method for reducing total inventory costs, which consist of ordering costs and holding costs, without disrupting the availability of spare parts to support dosing pump system maintenance activities.

The EOQ method provides a quantitative approach to determining optimal order quantities, while the POQ method focuses on setting more structured ordering intervals based on specific time cycles. The calculation of ordering costs, between actual, EOQ, and POQ, is presented in Table 4.22.

Table 4.22 Comparison of Ordering Costs (Actual, EOQ, POQ)

No	Spare parts	Actual (Units/Year)	EOQ (Units)	POQ (Interval)
1.	Power Cable	6	2	4-5 months
2.	Seal Bearing	5	2	5 months
3.	Shaft	4	1	3-4 months
4.	Bearing	5	3	7-8 months
5.	Gearbox	5	1	2-3 months
6.	Shaft Oil Seal	3	2	8 months
7.	Relay	10	4	5-6 months
8.	Fuse	4	2	6 months
9.	Filter	6	3	5 months
10.	Dosing Pipe	8	3	4-5 months
11.	Seal Clamp	4	2	6 months
12.	Level Sensor	5	2	5-6 months
13.	Strainer	8	4	6-7 months
14.	Suction Pipe	3	2	8 months
15.	Foot Valve	3	2	12 months
16.	Seal Valve	2	1	12 months
17.	Seal Pump	5	3	8 months
18.	Motor Cable	4	2	6 months
19.	Shaft Oil Ring	3	1	12 months
20.	Impeller	7	2	3-4 months
21.	PCB / Control Panel	10	1	1-2 months
22.	Pump Motor	12	2	2 months

Source: Primary data processed by researchers, 2026

In this study, the ordering cost was set at Rp100.000 per purchase, while the storage cost was based on the actual warehouse cost of Rp230.000 per month. The calculation was based on the number of orders for each spare part according to the company's actual conditions, the EOQ results, and the POQ ordering interval.

So the calculation of inventory costs per EOQ and POQ component is presented in more detail in Table 4.23.

Table 4.23 Comparison of Inventory Costs per Component

No	Spare parts	Actual OC	Actual HC	OC EOQ	HC EOQ
1	Power Cable	100,000	1,380,000	300,000	460,000
2	Seal Bearing	100,000	1,150,000	250,000	460,000
3	Shaft	100,000	920,000	400,000	230,000
4	Bearing	100,000	1,150,000	166,667	690,000
5	Gearbox	100,000	1,150,000	500,000	230,000
6	Shaft Oil Seal	100,000	690,000	150,000	460,000
7	Relay	100,000	2,300,000	250,000	920,000
8	Fuse	100,000	920,000	200,000	460,000
9	Filter	100,000	1,380,000	200,000	690,000

10	Dosing Pipe	100,000	1,840,000	266,667	690,000
11	Seal Clamp	100,000	920,000	200,000	460,000
12	Level Sensor	100,000	1,150,000	250,000	460,000
13	Strainer	100,000	1,840,000	200,000	920,000
14	Suction Pipe	100,000	690,000	150,000	460,000
15	Foot Valve	100,000	690,000	150,000	460,000
16	Seal Valve	100,000	460,000	200,000	230,000
17	Seal Pump	100,000	1,150,000	166,667	690,000
18	Motor Cable	100,000	920,000	200,000	460,000
19	Shaft Oil Ring	100,000	690,000	300,000	230,000
20	Impeller	100,000	1,610,000	350,000	460,000
21	PCB / Control Panel	100,000	2,300,000	1,000,000	230,000
22	Pump Motor	100,000	2,760,000	600,000	460,000

Source: Primary data processed by researchers, 2026

Based on the calculations above, the total inventory costs incurred for actual conditions, EOQ, and POQ can be summarized in Table 4.24 below:

Table 4.24 Total Inventory Costs

Cost Components	Actual (Rp)	EOQ (Rp)	POQ (Rp)
Order Fee	2,200,000	6,850,001	6,850,001
Storage Costs	28,110,000	10,810,000	10,810,000
Total cost	30,310,000	17,660,001	17,660,001

Source: Primary data processed by researchers, 2026

Based on the inventory cost comparison results in Table 4.24, it is known that the actual method produces the highest total inventory cost of Rp30,310,000 per year. This high cost is primarily due to the high storage costs resulting from a suboptimal spare part procurement pattern that is still reactive to damage. The EOQ method is able to reduce total inventory costs to Rp17.660,001 per year. This decrease occurs because EOQ can determine the optimal order quantity so that ordering costs and storage costs are at a more efficient balance point. Meanwhile, the POQ method produces a total cost that is relatively the same as EOQ because the order quantity remains based on the EOQ value. The difference lies in the more scheduled ordering intervals, allowing the company to plan spare part procurement in a more systematic and structured manner.

Analysis of Effectiveness and Efficiency

Effectiveness and efficiency analysis were conducted to evaluate the extent to which the implementation of the Reliability Centered Maintenance (RCM) method and improvements to the spare parts inventory management system through the EOQ and POQ approaches were able to improve the performance of the dosing pump system at PT Dain Celicani Cemerlang. Effectiveness in this study was measured based on the system's ability to reduce downtime and increase reliability and availability levels, while efficiency was measured based on the company's ability to reduce maintenance costs and spare parts inventory costs.

Based on the results of the previous analysis, it is known that the total actual system downtime reaches 526 hours per year. After implementing an RCM-based maintenance strategy, critical components such as Power Cables, Seal Bearings, Shafts, Bearings, Gearboxes, and Shaft Oil Seals

become the main focus of maintenance because these six components contribute approximately 72.24% of the total system downtime. Through the implementation of preventive maintenance, predictive maintenance, scheduled replacement, and condition-based maintenance strategies on these critical components, system downtime is estimated to be significantly reduced to near optimal conditions.

Reduction in downtime demonstrates that a reliability-based maintenance strategy is more effective than the company's current situation, which is still dominated by corrective maintenance. Previously, maintenance activities tended to be carried out after damage occurred, resulting in longer repair times and disrupting the continuity of the water treatment process. After implementing RCM, maintenance activities became more planned because they were based on the Risk Priority Number (RPN), Mean Time Between Failure (MTBF), and the failure characteristics of each component. Thus, potential damage can be detected earlier, increasing system availability and minimizing the risk of sudden breakdowns.

In terms of cost efficiency, the implementation of the EOQ and POQ methods also showed better results than the company's actual system. Based on previous calculations, the total inventory cost under actual conditions reached Rp30,310,000 per year, whereas after implementing the EOQ and POQ methods, the total inventory cost could be reduced to Rp17,660,001 per year. Thus, the company has the potential to achieve inventory cost savings of Rp12,649,999 or approximately 41.73%.

This cost reduction occurs because the EOQ method is able to determine the optimal number of spare part orders based on the balance between ordering costs and holding costs. Meanwhile, the POQ method helps companies determine more structured ordering intervals based on the actual needs of each component. With a more systematic ordering schedule, companies can reduce the risk of stockouts and excessive inventory buildup in the warehouse.

In addition to providing cost efficiencies, the integration of RCM and an EOQ-POQ-based inventory system also improves overall system reliability. More planned spare part availability allows for faster repairs when disruptions occur, reducing downtime. This demonstrates that inventory management plays a role not only in cost aspects but also directly contributes to improving the operational reliability of dosing pump systems.

Recommendations and Choice of Best Methods

Based on the overall results of the analysis that has been carried out, recommendations can be made for the best method that can be applied to the dosing pump system at PT Dain Celicani Cemerlang.

From a maintenance perspective, the Reliability Centered Maintenance (RCM) method is considered the most appropriate approach compared to the company's current system, which is still dominated by corrective maintenance. This is because RCM is able to identify critical components based on the level of failure risk (Risk Priority Number / RPN), Mean Time Between Failure (MTBF) value, and the impact of damage on the system. Through this approach, maintenance strategies can be determined in a more targeted manner, such as preventive maintenance, predictive maintenance, scheduled replacement, and condition-based maintenance (Simanungkalit et al., 2023).

The analysis results show that focusing maintenance on critical components such as Power Cables, Bearing Seals, Shafts, Bearings, Gearboxes, and Shaft Oil Seals can have a significant impact

on reducing downtime. These six components are known to contribute around 72.24% of the total system downtime, so the implementation of an RCM-based maintenance strategy on these components is considered effective in increasing the reliability and availability of the dosing pump system. In addition, the implementation of RCM also makes maintenance activities more planned so that the company is no longer completely dependent on repair actions after damage occurs.

Meanwhile, from an inventory management perspective, the Period Order Quantity (POQ) method is considered the most optimal method compared to the company's current system and the EOQ method. This is because POQ not only considers economical order quantities but also regulates periodic ordering intervals, making it easier to implement in company operations (Jovany et al., 2025). With a more structured ordering schedule, companies can maintain spare part availability as needed without having to maintain excessive stock.

Based on the previous calculation results, the EOQ and POQ methods were able to reduce total inventory costs from Rp30,310,000 in actual conditions to Rp17,660,001 per year. This cost reduction indicates that the planned inventory system is more efficient than the actual procurement pattern which is still reactive to breakdowns. In addition to being able to reduce storage costs, the POQ method also supports operational continuity because spare parts can be available according to the schedule of needs.

Nevertheless, the EOQ method can still be used as a supporting method, especially for components with high demand and high criticality levels such as pump motors, power cables, relays, and PCBs/control panels. The EOQ method provides flexibility in determining the optimal order quantity based on the balance of ordering costs and storage costs (Lestari, 2024), so it remains relevant for application to certain spare parts with relatively high demand patterns.

Overall, the combination of the RCM method for maintenance strategy and the POQ method supported by EOQ and MRP for inventory management is the best alternative recommended in this study. The integration of these methods can provide dual benefits: increasing system effectiveness by reducing downtime and increasing reliability, while simultaneously increasing efficiency by optimally controlling maintenance and inventory costs. Thus, the company can maintain the continuity of the water treatment process in a more reliable, economical, and planned manner.

CONCLUSION

The maintenance strategy for the dosing pump system at PT Dain Celicani Cemerlang was developed using the Reliability-Centered Maintenance (RCM) approach by evaluating critical components, failure modes, Risk Priority Number (RPN), Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and downtime impact. The existing maintenance practice is predominantly corrective, resulting in 84 failure events, 526 hours of downtime, 96.73% availability, and a 7-day operational reliability of only 40.36%. Power cables, bearing seals, shafts, bearings, gearboxes, and shaft oil seals were identified as the most critical components, accounting for 72.24% of total downtime. By implementing selective RCM, maintenance activities were optimized through preventive, predictive, condition-based, and scheduled replacement strategies tailored to component failure characteristics. This approach reduced downtime to 56.74 hours, increased equipment availability to 99.65%, and improved 7-day reliability to 84.83%, demonstrating the effectiveness of

RCM in enhancing dosing pump reliability and ensuring the continuity of the clean water supply system.

The spare parts ordering policy was optimized by integrating RCM with the Economic Order Quantity (EOQ), Periodic Order Quantity (POQ), and Material Requirements Planning (MRP) methods to ensure timely and cost-effective spare parts procurement. The existing inventory system was found to be inadequate because several critical components lacked backup stock, increasing the risk of prolonged downtime during failures. The implementation of selective RCM reduced maintenance costs from Rp16,800,000 to Rp12,723,000, representing a 24.27% cost reduction. Furthermore, the combined EOQ and POQ approaches decreased annual inventory costs from Rp30,310,000 to Rp17,660,001, yielding savings of Rp12,649,999 (41.73%). Among the evaluated methods, POQ proved to be the most suitable because it determines not only economical order quantities but also optimal replenishment intervals. Supported by MRP, this integrated approach enables systematic spare parts planning, improves the availability of critical components, minimizes downtime, and enhances the overall reliability of the clean water supply system.

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