An Integrated IPMS–MAFMA Framework for Improving the Operational Efficiency of Clean Water Distribution Pump Systems

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DOI: https://doi.org/10.31284/j.jtm.2026.v7i2.9234
Received July 11th 2026; Received in revised July 13th 2026; Accepted July 24th 2026; Available online July 29th 2026

Abstract

PT. XYZ is a local government-owned company responsible for providing clean water services to the residents of Surabaya. To ensure reliable water distribution, the company must maintain high operational performance of its distribution pump system. However, operational activities are frequently disrupted by equipment failures and inadequate maintenance practices, resulting in reduced efficiency and service reliability. This study aims to improve operational performance and minimize machine failures by integrating the Integrated Performance Measurement System (IPMS) and Multi-Attribute Failure Mode Analysis (MAFMA) at the Central Distribution Pump House. The IPMS method was employed to identify and prioritize Key Performance Indicators (KPIs) requiring performance improvement based on their relative weights. Subsequently, the MAFMA method was applied to identify potential failure modes, evaluate associated risks, and determine appropriate corrective actions. The results indicate that KPI 9, namely the completion of non-routine maintenance work, obtained the highest priority weight of 0.174, indicating that it should be the primary focus for performance improvement. Furthermore, the MAFMA analysis identified a damaged foot valve as the most critical failure mode, with the highest Risk Priority Number (RPN) of 168. Based on these findings, the proposed improvements include developing contingency plans to manage unexpected priority changes and implementing routine inspection and cleaning of pump components every two days to reduce the likelihood of equipment failure. The integration of IPMS and MAFMA provides a systematic approach for enhancing maintenance performance, improving operational reliability, and supporting sustainable clean water services.

Keywords: *Failure, IPMS, MAFMA, Priority, Quality.*

1. Introduction

In the production process, companies generally have a department responsible for quality control. To overcome this problem, steps that can be taken include implementing a quality control system to reduce the likelihood of product defects and achieve a zero-defect level [1]. Quality control is an improvement strategy that helps companies maintain and enhance product quality standards by reducing product defects to achieve zero defects [2]. Quality is a key factor in consumer purchasing decisions for various products. Many companies believe that to compete globally, they must produce high-quality products. Continuous improvement efforts are needed for products, workers, processes, and the environment to achieve the highest quality [3-4].

Failure is when the actual results or conditions do not match what is expected. The process is a series of steps or actions involving technology that changes an initial object into one with different values and characteristics, usually more valuable [5]. In this context, process failure occurs when the process results do not match expectations, and it can be caused by events or factors that affect the benefits the process provides [6].

PT. XYZ is a local government company focused on clean water treatment. This company has direct responsibility for the community around Surabaya, and the community has high expectations for the quality of the products and services it provides. However, in an effort to improve the operational performance of distribution pumps to provide clean water to the community, the company often faces obstacles such as machine and production facility failures, which can impact the system's performance. Distribution pump machines operate at a very high level, so pump operations are replaced once a week to prevent damage. The pump machines are old, resulting in lengthy maintenance, and some spare parts are not always in stock. This results in significant downtime, so the machine cannot be used for an extended period. If the machine and components are damaged, performance will decrease, so the amount of water discharged will not match the target set for distributing clean water to consumers. Following a review of the problems that occurred, an analysis was conducted to improve the water distribution process at the Central Distribution Pump House using the IPMS (Integrated Performance Measurement System) and MAFMA (Multi-Attribute Failure Mode Analysis) methods.

The Integrated Performance Measurement System (IPMS) is a method for measuring company performance comprehensively through a top-down approach, with attention to each stakeholder's needs and continuous monitoring of the company's position in the competition [7],[8]. Research on measuring company performance using the IPMS method has been conducted extensively on a range of topics. Research by [9] demonstrated that implementing IPMS in educational institutions successfully identified 21 KPIs, grouped into 8 main criteria, that describe the overall performance of the school and serve as the basis for determining priorities for continuous improvement. Another study applied IPMS at the National Zakat Agency (BAZNAS) in Garut Regency using a stakeholder-based approach to evaluate organizational performance and support more effective decision-making [10]. Implementation in health service organizations shows that the IPMS method functions not only as a performance measurement tool but also as a management mechanism that encourages cross-functional collaboration to improve coordination, resulting in continuous improvement in service quality [11]. Another study developed an integration model linking the Balanced Scorecard (BSC) and IPMS to optimize company performance measurement by designing a more holistic measurement framework [12]. Overall, the existing research shows that the IPMS method is considered capable of improving company performance by analyzing unmet KPIs, implementing continuous improvement by identifying areas for improvement, and providing a basis for measuring the effectiveness of the corrective actions taken.

MAFMA is a development of the Failure Mode and Effects Analysis (FMEA) method that overcomes the limitations of determining risk priorities by incorporating expected costs, derived through the Analytical Hierarchy Process (AHP), resulting in a more comprehensive risk assessment [2],[13]. In MAFMA, potential causes of failure are assessed based on the highest weighted value. This method combines four factors in FMEA, namely the possibility of failure (occurrence), the possibility of non-detection (chance of non-detection), severity (severity), and expected cost, to obtain priority risk criteria for developing a company's risk mitigation strategy [14]. In the Financial Technology (FinTech) sector, research by [15] expanded the application of MAFMA to the operational risk analysis of the MyBeb digital payment application. The research proved that MAFMA is effective for evaluating risks in information technology-based systems. All studies show that the MAFMA method is more comprehensive and can produce more objective risk priorities across sectors, supporting more effective improvement decision-making.

This study aims to improve company performance by identifying asset maintenance needs and measuring employee performance through Integrated Performance Measurement Systems. This method is expected to prevent machine failures in clean water distribution and improve the performance of the production process. The MAFMA method is used to determine the highest potential failure value by adding expected costs for machine maintenance or handling, prioritizing improvements to the performance of the clean water distribution process. This study also involved Focus Group Discussions to determine the costs of maintenance or repair for identified failures.

2. Method

2.1 Integrated Performance Measurement System (IPMS)

IPMS, as a dynamic and balanced system, provides a comprehensive perspective through various measurements. This approach is used to evaluate company performance holistically and hierarchically, taking into account each stakeholder's needs and monitoring the company's position in the competitive context. The goal of the IPMS model is to improve the accuracy, effectiveness, and efficiency of performance measurement. The IPMS model establishes stakeholder desires as the starting point for achieving this goal [7]. The steps in measuring performance using the Integrated Performance Measurement System (IPMS) [12] are:

1. Identify stakeholders and list the needs of each stakeholder involved.
2. Establish the business objectives to be achieved.
3. Define the Key Performance Indicators (KPIs) that will be used to measure the level of achievement of business objectives.
4. Validate to ensure that the selected KPIs meet the performance measurement needs.
5. Specify each KPI, detailing how the KPI will be measured, including the data sources used and relevant measurement methods.
6. Weighting KPIs, namely providing a weight or relative level of importance for each KPI to describe the level of priority and its impact on achieving business goals.

2.2 Key Performance Indicator (KPI)

A Key Performance Indicator (KPI) is a tool used by organizations to measure and assess progress toward organizational goals [8]. KPIs are used primarily to evaluate activities that are difficult to quantify, such as profitability, leadership, engagement, service, and satisfaction. KPIs are essential elements of objectives that can be measured objectively and consist of indicators aligned with the organization's strategy. When developing KPIs, it is necessary to establish clear, measurable performance indicators. The objectives of KPI-based performance assessments are as follows:

1. A comprehensive evaluation of the health and well-being of an organization.
2. Focusing on critical/vital aspects of organizational performance on an ongoing basis, with a focus on achieving future success.
3. Measuring success in areas deemed crucial for impacting customers, employees, and stakeholders.
4. The importance of building an organization-wide, individual department, and individual teams capable of at least identifying Key Performance Indicators (KPIs).

2.3 Analytical Hierarchy Process (AHP*)*

According to [16], the AHP method, introduced by Thomas L. Saaty in the 1970s, is an effective tool for decision-making. This approach has been widely used for critical decisions. The advantage of AHP lies in its ability to prioritize options based on previously identified criteria. Essentially, AHP helps address complex problems by constructing a hierarchy of criteria, eliciting subjective assessments from stakeholders, and synthesizing diverse considerations to derive weights or priorities. The steps in solving a problem using the AHP method are as follows [17]:

1. Problem identification and hierarchy creation
   The Analytical Hierarchy Process (AHP) begins with identifying the problem, then decomposing it into basic elements such as action options, attributes, or criteria. These elements are used to prioritize or rank the various possible solutions.
2. Pairwise comparison
   The importance of hierarchy elements is determined by assigning priorities/weights using the pairwise comparison method. This method uses a scale from 1 (both elements are equally important) to 9 (one element is absolutely more important than the other) to express the level of importance of each element. Criteria are weighted according to their level of importance in achieving the goal. Each alternative is weighted against each criterion.
3. Calculating Matrix Normalization:
   a. Add the values of each column in the pairwise comparison matrix.
   b. Divide each column value by the corresponding column total to obtain the matrix normalization, as shown in the equation below.:

   $$m = \frac{Ci,j}{C1} \qquad \text{..………(1)}$$

   Where:

m: normalization result
Cj: sum of each column
Ci: fixed cell value

4. Calculate the priority weight
Add the values from the rows and divide the result by the number of elements to obtain the priority weight value shown in the following equation:
$$bp = \frac{Rj}{R} \quad \text{.........(2)}$$
Where:
bp : average result / priority weight
©Rj : number of each row
©R : number of criteria

5. Calculate the maximum eigenvalue:
   a. Multiply each cell value in the first column by its priority weight, the value in the second column by its second priority weight, and so on. This is done to assign weights to each element in the comparison matrix.
   b. Sum the results of each row in the comparison matrix. This is done to obtain the total weights for each row.
   c. Divide the sum of each row by the corresponding relative priority element. The goal is to obtain the average relative weight for each element in that row.
   d. Sum the results from the previous step (λ) for each criterion and divide the result by the number of elements. The result is called λmax, which is shown in the equation below.:
   $$\lambda_{max} = \frac{\Sigma \quad \lambda}{n} \quad \text{.........(3)}$$
   Where:
   λ_{max} : maximum eigenvalue
   n : number of criteria

6. Calculate the consistency index (CI) using the following equation:
$$CI = \frac{\lambda_{max-} n}{n-1} \quad \text{....... .....(4)}$$

7. Calculate the consistency ratio (CR) using the equation below
$$CR = \frac{CI}{RI} \quad \text{..........(5)}$$
Where:
CR : consistency ratio
RI : random index
If the CR value exceeds 0.1, the assessment data is inconsistent and needs to be corrected. On the other hand, if the CR value is less than 0.1, the data calculation is considered consistent. RI is a random index value shown in Table 1.

Table 1. Random index values

Matrix size (N)	Value RI	Matrix size (N)	Value RI
1, 2	0	9	1,45
3	0,58	10	1,49
4	0,90	11	1,51
5	1,12	12	1,48
6	1,24	13	1,56
7	1,32	14	1,57
8	1,41	15	1,59

2.4 Multi Attribute Failure Mode Analysis *(*MAFMA)

The Multi-Attribute Failure Mode Analysis (MAFMA) method is used to analyze and prioritize failures more effectively and efficiently. In the MAFMA process, the initial step is to determine local priorities by considering three criteria: severity, the possibility of failure (change of failure), and the

possibility of failure not being detected (detectability) [14]. MAFMA uses four working criteria as the basis for processing, namely:
1. Chance of failure: describes the probability of a failure occurring in a system.
2. Chance of non-detection: indicates the extent to which a failure can occur without being detected during inspection or testing.
3. Failure severity: evaluates the impact or consequence of the failure on the system or process involved.
4. Expected cost: reflects the estimated costs associated with the failure, including repair costs, damage costs, or other losses.

In this study, MAFMA is a method that combines FMEA and Focus Group Discussion (FGD). The FGD method is used to address FMEA's weakness in accounting for the handling costs of each failure by discussing them with the production maintenance team. The following are the stages of the MAFMA method in this study:
1. Identify the causes of failure at the Ngagel Distribution Pump House.
2. Create a Failure Mode and Effects Analysis (FMEA) table by including all causes of failure. The Failure Mode and Effects Analysis (FMEA) method was applied to assess the three principal risk factors, namely Severity (S), Occurrence (O), and Detection (D), which represent the impact of a failure, the likelihood of its occurrence, and the ability to detect the failure before it results in adverse consequences, respectively [18].
3. Calculate the Risk Priority Number (RPN) using the formula S x O x D to determine the priority of failure risks for corrective action.
4. Conduct a Focus Group Discussion (FGD) with several participants to discuss the costs of handling each cause of failure.

2.5 Focus Group Discussion *(FGD)*

Focus Group Discussion (FGD) is a qualitative data collection technique involving a structured group discussion centered on a specific issue or research topic. It is conducted in an informal setting with a limited number of participants and facilitated by a moderator to encourage open and interactive communication. As a qualitative research approach, FGD complements other data collection methods, such as direct observation and in-depth interviews. To ensure an effective discussion, adequate preparation should be undertaken to minimize potential barriers that may hinder participant interaction. Before the discussion begins, the moderator should clearly explain the objectives, procedures, and discussion guidelines, and facilitate the session according to the established protocol. At the conclusion of the discussion, the moderator summarizes the key findings, reviews the overall discussion process, and solicits feedback from all participants to improve the implementation of subsequent FGD sessions [19].

3. Results and Discussion

3.1 Identification of Key Performance Indicators

The identification of Key Performance Indicators (KPIs) was conducted to determine the performance measures required for evaluating the activities of employees in the Production Maintenance Division. The KPIs were identified based on interviews and discussions with experts and key personnel involved in the decision-making process (expert judgment) within the Production Maintenance Division. The identification process resulted in 11 Key Performance Indicators, which are presented in Table 2

Table 2. Key Performance Indicators of the Production Maintenance Division at IPAM Ngagel 1

KPI Code	KPI	Objective	KPI Specification
KPI 1	Work Program Implementation	Improve maintenance and repair activities	Number of investment work programs that have been converted into Work Orders (service contracts)

KPI Code	KPI	Objective	KPI Specification
KPI 2	Complaint Resolution Rate	Improve maintenance response and repair implementation	Number of customer complaints received during month *n*
KPI 3	Maintenance Asset Availability and Reliability	Improve the availability and reliability of maintenance assets and equipment	Percentage of maintenance asset availability and reliability
KPI 4	Preventive Work Order – Monitoring	Monitor the condition of machines and production assets	Number of monitoring activities completed
KPI 5	Preventive Work Order – Routine Maintenance	Improve machine and asset performance	Number of routine maintenance activities completed
KPI 6	Corrective Work Order – Non-Routine Maintenance	Improve maintenance activities for supporting components	Number of non-routine maintenance work orders completed
KPI 7	Corrective Work Order – Monitoring-Based Repairs	Improve continuous corrective maintenance	Number of corrective work orders generated from monitoring activities
KPI 8	Corrective Work Order – Complaint-Based Repairs	Improve corrective actions for machine and asset failures	Number of corrective work orders generated from customer complaints
KPI 9	Completion of Non-Routine Maintenance Work	Improve the completion of maintenance activities for supporting asset	Percentage of non-routine maintenance work completed
KPI 10	Completion of Monitoring-Based Repair Work	Improve the completion of machine and asset repair activities identified through monitoring	Percentage of monitoring-based repair work completed
KPI 11	Completion of Complaint-Based Repair Work	Achieve the target completion of repairs resulting from customer complaints	Percentage of complaint-based repair work completed

3.2 KPI Weighting Using the Analytical Hierarchy Process (AHP)

The priority weights of the Key Performance Indicators (KPIs) were determined using the Analytical Hierarchy Process (AHP). The first step involved calculating the maximum eigenvalue (λ_{max}) through matrix multiplication of the pairwise comparison matrix. The resulting eigenvalue was subsequently used to calculate the Consistency Index (CI) and Consistency Ratio (CR) to assess the consistency of the pairwise comparison judgments. According to Saaty's consistency criterion, the pairwise comparisons are considered acceptable when the Consistency Ratio (CR) is less than or equal to 0.10. The complete calculation results are presented in Figure 1.

Total eigen value = 15.398 + 8.568 + 12.135 + 11.722 + 6.879 + 5.132 + 7.762 + 12.640 + 4.397 + 9.218 + 12.930 = 106.7823

Average Eigenvalue = 106.7823/11 = 9.707

Consistency Index (CI) = (9.707-11)/(11-1) = 0.1300

Consistency Ratio (CR) = 0.1300/1.51 = 0.086

The calculation results indicate that the Consistency Ratio (CR) for the pairwise comparison matrix is 0.086, which is below the acceptable threshold of 0.10. Therefore, the pairwise comparison judgments among the KPIs are considered consistent, indicating that the derived priority weights are sufficiently reliable for subsequent analysis.

Subsequently, the KPI weighting process was carried out to determine the relative importance of each Key Performance Indicator (KPI). This stage involved evaluating pairwise comparison questionnaires based on the Analytic Hierarchy Process (AHP), which were completed by the management of the Production Maintenance Division. The KPI priority weights were calculated using pairwise comparison matrices with the support of Expert Choice version 11 software. The results of the weighting analysis are presented in Figure 2.

$$A\,x = \lambda_{max} x$$

$$\overset{A}{\left|\begin{matrix} 1.00 & 0.85 & 0.55 & 0.15 & 0.56 & 1.64 & 0.49 & 0.47 & 0.79 & 0.77 & 0.16 \\ 0.85 & 1.00 & 3.42 & 0.36 & 0.41 & 1.51 & 1.05 & 0.75 & 3.68 & 0.28 & 0.28 \\ 0.55 & 3.42 & 1.00 & 0.18 & 0.15 & 0.49 & 0.49 & 0.17 & 1.71 & 0.75 & 0.54 \\ 0.15 & 0.36 & 0.18 & 1.00 & 2.41 & 5.52 & 0.55 & 0.52 & 2.11 & 0.59 & 0.17 \\ 0.56 & 0.41 & 0.15 & 2.41 & 1.00 & 2.11 & 3.56 & 0.24 & 5.31 & 4.22 & 0.52 \\ 1.64 & 1.51 & 0.49 & 5.52 & 2.11 & 1.00 & 0.55 & 0.15 & 5.65 & 1.41 & 3.27 \\ 0.49 & 1.05 & 0.49 & 0.55 & 3.56 & 0.55 & 1.00 & 2.52 & 5.94 & 0.85 & 0.50 \\ 0.47 & 0.75 & 0.17 & 0.52 & 0.24 & 0.15 & 2.52 & 1.00 & 1.82 & 0.56 & 1.06 \\ 0.79 & 3.68 & 1.71 & 2.11 & 5.31 & 5.65 & 5.94 & 1.82 & 1.00 & 1.44 & 0.14 \\ 0.77 & 0.28 & 0.75 & 0.59 & 4.22 & 1.41 & 0.85 & 0.56 & 1.44 & 1.00 & 1.52 \\ 0.16 & 0.28 & 0.54 & 0.17 & 0.52 & 3.27 & 0.50 & 1.06 & 0.14 & 1.52 & 1.00 \end{matrix}\right|} \times \overset{x}{\left|\begin{matrix} 0.04954 \\ 0.08904 \\ 0.06287 \\ 0.06508 \\ 0.11090 \\ 0.14865 \\ 0.09829 \\ 0.06035 \\ 0.17350 \\ 0.08276 \\ 0.05900 \end{matrix}\right|} = \overset{Ax}{\left|\begin{matrix} 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \\ 0.76290 \end{matrix}\right|} = \lambda_{max} \overset{x}{\left|\begin{matrix} 0.04954 \\ 0.08904 \\ 0.06287 \\ 0.06508 \\ 0.11090 \\ 0.14865 \\ 0.09829 \\ 0.06035 \\ 0.17350 \\ 0.08276 \\ 0.05900 \end{matrix}\right|} \rightarrow \overset{\lambda_{max}}{\left|\begin{matrix} 15.398 \\ 8.568 \\ 12.135 \\ 11.722 \\ 6.879 \\ 5.132 \\ 7.762 \\ 12.640 \\ 4.397 \\ 9.218 \\ 12.930 \end{matrix}\right|}$$

Figure 1. AHP Calculation

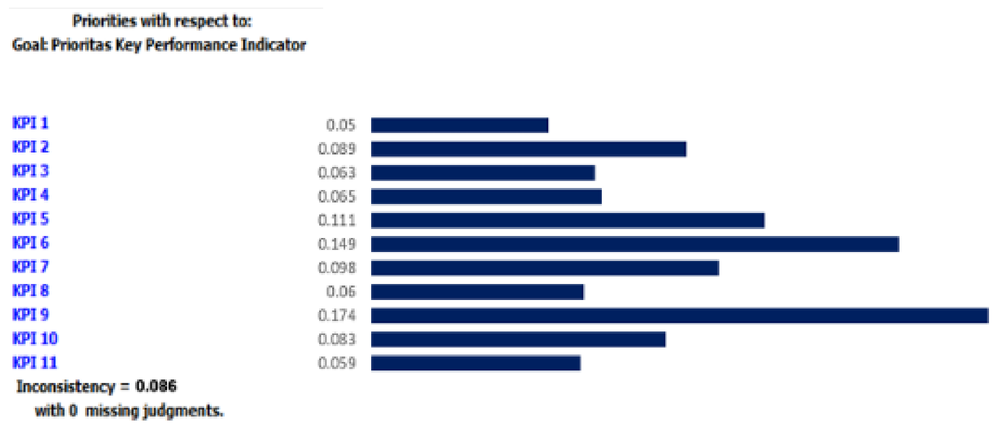

Figure 2. KPI weighting results with Expert Choice Software

The resulting weight values represent the priority level of each KPI in supporting efforts to prevent potential failures. A higher weight indicates that the corresponding KPI is more critical and should receive greater attention in the implementation of performance improvement initiatives. Therefore, KPIs with higher priority weights should be addressed first through appropriate corrective actions. A summary of the overall KPI weight values is presented in Table 3.

Table 3. Recapitulation of KPI Priority Weights

Key performance indicator (KPI)	Priority Weight
Work Program Implementation	0.050
Complaint Resolution Rate	0.089
Maintenance Asset Availability and Reliability	0.063
WO Preventive Monitoring	0.065
Preventive Work Order – Routine Maintenance	0.111
Corrective Work Order – Non-Routine Maintenance	0.149
Corrective Work Order – Monitoring-Based Repairs	0.098
Corrective Work Order – Complaint-Based Repairs	0.060
Completion of Non-Routine Maintenance Work	**0.174**
Completion of Monitoring-Based Repair Work	0.083
Completion of Complaint-Based Repair Work	0.059
Total	1.000
Consistency Ratio (CR)	0.086093
Conclusion	Consisten

As presented in Table 3, the KPI "Completion of Non-Routine Maintenance Work" obtained the highest priority weight (0.174), indicating that this performance indicator has the greatest influence on the overall effectiveness of the Production Maintenance Division. This finding suggests that improving the timeliness and completion of non-routine maintenance activities should become the primary focus for enhancing operational performance. Conversely, Work Program Implementation received the lowest priority weight (0.050), indicating a relatively smaller contribution to maintenance performance compared with the other KPIs. The calculated Consistency Ratio (CR) of 0.086 satisfies Saaty's consistency criterion ($CR \leq 0.10$), confirming that the pairwise comparison judgments are sufficiently consistent and that the resulting priority weights are reliable for subsequent failure analysis.

3.3 Identification of Potential Failure Modes for the Priority KPI

Based on the KPI weighting results, KPI 9 was identified as the highest-priority indicator, having the largest weight value. Therefore, this KPI was selected for further evaluation. The next stage involved identifying potential failure modes associated with the prioritized KPI through the analysis of work order data. These data included maintenance requests, complaints, and written reports related to maintenance activities. The work order data were analyzed to identify the most frequent potential failures occurring during maintenance operations. The identified potential failure modes associated with the highest-priority KPI are presented in Table 4.

Table 4. Analysis of the Highest-Priority KPI and Its Potential Failure Mode.

Key Performance Indicator (KPI)	Identified Problems	Potential Failure Mode
KPI 9 Completion of Non-Routine Maintenance Work	1. Delays due to changes in maintenance priorities. 2. Unsatisfactory completion of maintenance activities. 3. Inadequate planning and supervision of maintenance resources. 4. Shortage of qualified maintenance personnel. 5. Limited availability of spare parts and maintenance equipment	1. Pump trip. 2. Excessive vibration. 3. Motor overheating. 4. Coupling failure. 5. Coupling rubber wear. 6. Abnormal operating noise. 7. Gearbox failure. 8. Foot valve failure. 9. Pump leakage. 10. Worn pump bearing

The analysis of complaints and maintenance reports compiled in the Work Order records identified ten potential failure criteria that frequently occurred at the Central Ngagel 1 Distribution Pump House. These identified failure criteria were subsequently evaluated using the Failure Mode and Effects Analysis (FMEA) method to determine the magnitude of their potential risks. The evaluation results were used to identify the failure modes with the highest risk priority, thereby providing a basis for implementing appropriate preventive and mitigation measures to minimize the adverse effects of equipment failures

3.4 Failure Mode and Effects Analysis (FMEA) Results

At this stage, the Risk Priority Number (RPN) for each identified failure mode was calculated based on the assessment results obtained from questionnaires distributed to experts in the Production Maintenance Division of IPAM Ngagel 1, Surabaya. The RPN value was determined by multiplying the three principal FMEA parameters, namely Severity (S), Occurrence (O), and Detection (D). The resulting RPN values were subsequently used to prioritize maintenance problems requiring corrective actions. A higher RPN indicates a greater level of risk and, therefore, a higher priority for mitigation. The complete results of the FMEA evaluation are presented in Table 5.

Table 5. Results of the Failure Mode and Effects Analysis (FMEA)

Failure mode	Failure Effect	S	O	D	RPN
Pump trip	Failure to deliver water to the distribution network	7	4	4	112

Failure mode	Failure Effect	S	O	D	RPN
Excessive vibration	Unstable pump operation due to excessive vibration	5	5	2	50
Motor overheating	Potential overheating and burnout of the electric motor	7	4	3	84
Coupling failure	Pump becomes inoperable	7	3	3	63
Coupling rubber wear	Excessive vibration during pump operation	3	6	2	36
Abnormal operating noise	Excessive vibration causing deterioration of the coupling rubber	3	5	2	30
Gearbox failure	Suction pipe cannot remain fully primed	4	6	5	120
Foot valve failure	**Suction pipe cannot remain fully primed**	7	4	6	**168**
Pump leakage	Significant loss of distributed water	2	4	2	16
Worn pump bearing	Excessive vibration and abnormal operating noise	7	5	4	140

The FMEA results indicate that foot valve failure is the most critical failure mode, with the highest Risk Priority Number (RPN) of 168. This failure prevents the suction pipeline from remaining fully primed, thereby reducing the operational performance of the water distribution pump and potentially interrupting the continuity of water supply.

Given its highest risk level, foot valve failure was selected as the primary focus for further risk evaluation. In the subsequent stage, the expected cost associated with this failure mode was incorporated into the analysis to establish a more comprehensive prioritization of maintenance actions using the Multi-Attribute Failure Mode Analysis (MAFMA) approach. The expected cost was determined through a Focus Group Discussion (FGD) involving maintenance experts and production personnel, enabling the development of practical and economically feasible corrective actions aimed at minimizing the impact of this critical failure.

3.5 Focus Group Discussion (FGD)

Following the identification of the most critical failure mode through the FMEA analysis, a Focus Group Discussion (FGD) was conducted to estimate the expected maintenance cost associated with the highest-priority failure. The discussion involved maintenance supervisors, production engineers, and experienced technicians from the Production Maintenance Division of IPAM Ngagel 1.

The primary objective of the FGD was to obtain expert consensus regarding the estimated cost required to repair or replace the critical component identified during the FMEA stage. The estimated maintenance cost represents an additional decision attribute incorporated into the Multi-Attribute Failure Mode Analysis (MAFMA) framework, enabling a more comprehensive assessment of maintenance priorities by considering both technical risk and economic consequence.

The FGD results indicate that the foot valve failure, which obtained the highest Risk Priority Number (RPN), requires an estimated maintenance cost of IDR 30,000,000 for a single repair event. The summary of the FGD results is presented in Table 6.

Table 6. Estimated Maintenance Cost Obtained from Focus Group Discussion

Potential failure	Failure Effect	RPN	Estimated Maintenance Cost (per Repair)
Foot valve failure	The suction pipeline cannot remain fully primed	168	Rp. 30.000.000

3.6 Multi-Attribute Failure Mode Analysis (MAFMA) Results

The Multi-Attribute Failure Mode Analysis (MAFMA) was employed to integrate the technical risk identified through the FMEA analysis with the economic impact represented by the estimated maintenance cost obtained from the Focus Group Discussion. Unlike conventional FMEA, which prioritizes failure modes solely based on the Risk Priority Number (RPN), MAFMA incorporates an additional decision attribute—expected maintenance cost—to provide a more comprehensive basis for maintenance prioritization.

The integration of these two attributes enables maintenance decision-makers to evaluate not only the likelihood and severity of equipment failures but also the financial implications associated with corrective actions. Consequently, maintenance resources can be allocated more effectively by balancing operational risk and maintenance expenditure.

The MAFMA results confirm that foot valve failure remains the highest-priority failure mode. In addition to having the highest Risk Priority Number (168), this failure also requires a substantial maintenance expenditure of approximately IDR 30,000,000 per repair. Therefore, foot valve failure represents the most critical maintenance issue requiring immediate corrective and preventive actions.

The integration of the IPMS and MAFMA approaches provides a comprehensive maintenance decision-support framework. While IPMS identifies the most critical performance indicator requiring improvement, MAFMA determines the failure mode that should receive the highest maintenance priority by simultaneously considering operational risk and expected maintenance cost.

3.7 Proposed Improvement Strategy Based on the Integrated IPMS–MAFMA Framework

Based on the integration of the Integrated Performance Measurement System (IPMS) and the Multi-Attribute Failure Mode Analysis (MAFMA), the highest-priority Key Performance Indicator (KPI) and the most critical failure mode were identified as the primary focus for performance improvement. The IPMS analysis revealed that KPI 9 (Completion of Non-Routine Maintenance Work) received the highest priority weight, while the MAFMA analysis identified foot valve failure as the most critical failure mode due to its high technical risk and significant maintenance cost.

These findings provide the basis for developing an integrated improvement strategy that simultaneously addresses organizational performance and equipment reliability. The proposed improvement strategies derived from the IPMS and MAFMA analyses are summarized in Table 7.

Table 7. Proposed Improvement Strategies Based on the Integrated IPMS–MAFMA Framework

Integrated performance measurement system (IPMS)		
(KPI)	**Identified Problems**	**Proposed improvements**
KPI 9 Completion of Non-Routine Maintenance Work	1. Delays caused by changes in maintenance priorities 2. Unsatisfactory completion of maintenance activities 3. Inadequate planning and supervision of maintenance resources 4. Shortage of qualified maintenance personnel. 5. Limited availability of spare parts and maintenance equipment	1. Develop contingency plans to accommodate unexpected changes in maintenance priorities, thereby minimizing maintenance delays.. 2. Conduct post-maintenance quality inspections to ensure that all completed work complies with the established maintenance standards. 3. Perform periodic progress monitoring to ensure that maintenance resources are allocated according to the maintenance plan 4. Increase the number of qualified maintenance personnel and provide technical training to existing staff to improve their capability in handling equipment failures 5. Improve the spare parts management system and strengthen coordination with suppliers and vendors to ensure the timely availability of maintenance components.
Multi attribute failure mode analysis (MAFMA)		
Failure Mode	***Root Cause***	**Proposed Improvement Strategies**
Foot valve rusak	1. High operating frequency 2. Poor material quality 3. Dust and debris accumulation	1. Repair or refurbish the damaged foot valve whenever feasible 2. Replace the component when repair is no longer technically or economically viable 3. Implement a preventive maintenance program involving inspection and cleaning of the foot valve every two days to reduce the likelihood of recurring failures

The proposed improvement strategy demonstrates the complementary roles of the IPMS and MAFMA approaches in supporting maintenance decision-making. While the IPMS framework identifies the organizational performance indicator that requires immediate attention, the MAFMA approach determines the failure mode that should receive the highest maintenance priority by considering both technical risk and economic consequence.

The integration of these two approaches enables the organization to develop improvement strategies from two complementary perspectives. At the managerial level, the proposed actions focus on improving maintenance planning, resource allocation, workforce competency, and spare parts management. At the operational level, the recommendations emphasize preventive maintenance activities, including routine inspection, cleaning, refurbishment, and timely replacement of critical components, particularly the foot valve.

Consequently, the proposed framework not only enhances maintenance performance but also improves equipment reliability, reduces operational downtime, and supports the sustainable operation of the clean water distribution system

4. Conclusion

The results of the Integrated Performance Measurement System (IPMS) analysis indicate that KPI 9 (Completion of Non-Routine Maintenance Work) obtained the highest priority weight (0.174), demonstrating that the timeliness and effectiveness of non-routine maintenance activities are the most influential factors affecting the performance of the Production Maintenance Division. This finding suggests that improving the efficiency of non-routine maintenance through better resource allocation, maintenance scheduling, and operational control should become the primary focus for enhancing maintenance performance.

The Multi-Attribute Failure Mode Analysis (MAFMA) identified foot valve failure as the most critical failure mode, with the highest Risk Priority Number (RPN) of 168. This failure represents the greatest operational risk to the clean water distribution system and therefore requires immediate attention. Based on the MAFMA results, the proposed improvement strategies include the development of a contingency plan to accommodate unexpected changes in maintenance priorities and minimize maintenance delays, as well as the implementation of a preventive maintenance program involving inspection and cleaning of the foot valve every two days to reduce the likelihood of recurring failures

The integration of the Integrated Performance Measurement System (IPMS) and Multi-Attribute Failure Mode Analysis (MAFMA) provides a comprehensive decision-support framework for maintenance performance improvement. The IPMS approach identifies the key performance indicators that require priority improvement, whereas MAFMA determines the most critical failure modes by simultaneously considering technical risk and maintenance cost. Consequently, the proposed integrated framework enables organizations not only to prioritize performance improvement initiatives but also to identify the root causes of operational risks and implement appropriate mitigation strategies. This integrated approach contributes to improving maintenance effectiveness, reducing equipment downtime, and enhancing the operational reliability of clean water distribution systems.

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How to cite this article:
Hariastuti N L P, Irfan M. An Integrated IPMS–MAFMA Framework for Improving the Operational Efficiency of Clean Water Distribution Pump Systems. *Jurnal Teknologi dan Manajemen.* 2026 July; 7(2): 99-110. DOI: 10.31284/j.jtm.2026.v7i2.9234