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Research Paper

# Service Reliability and Downtime Mitigation: An Assessment of Electric Cooperative's Maintenance Operations in Negros Occidental, Philippines

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**Abstract**

Effective maintenance of distribution facilities is essential to sustaining reliable electricity service and addressing recurring interruptions. This study aimed to assess maintenance operations, their relationship with perceived service reliability and downtime mitigation, and maintenance challenges in an electric cooperative in Negros Occidental, Philippines. The findings served as the basis for a proposed maintenance operations improvement framework. Anchored in the Reliability-Centered Maintenance framework, the study used a quantitative descriptive-correlational design with 98 respondents selected through simple random sampling from 130 qualified personnel. The study collected data using a structured questionnaire and used Spearman's rank-order correlation to examine the relationship between the principal variables. Findings showed very high implementation of maintenance operations and very high perceived service reliability and downtime mitigation, with a strong positive and statistically significant relationship between them. Maintenance challenges were moderate overall, with aging facilities, limited monitoring technology, and response delays identified as the leading concerns. The study concluded that maintenance practices were extensively implemented, but equipment, technology, and response limitations required targeted improvements. Higher maintenance ratings were associated with better perceived service outcomes, but the study did not establish causation or actual reductions in downtime. The proposed framework emphasized risk-based line clearing, equipment condition assessment, diagnostic monitoring, resource allocation, and evaluation using operational records. It gives management a basis to prioritize maintenance needs and track improvements through recorded interruption and restoration data.

**Keywords**: *Electric Cooperative Maintenance, Electrical Distribution System Maintenance, Negros Occidental, Philippines, Perceived Electricity Service Reliability, Power Interruption Mitigation, Preventive Maintenance, Reliability-Centered Maintenance*

## INTRODUCTION

Reliable electricity service is essential to households, businesses, government services, and productive activities that depend on a continuous power supply. In electric cooperatives, service reliability is closely tied to the condition and management of distribution assets because equipment deterioration, faults, and restoration delays can interrupt electricity delivery. Maintenance operations therefore play an important role in preserving the operating condition of electrical facilities, detecting developing defects, responding to failures, and supporting timely restoration. Assessing these operations can help identify maintenance practices and operational challenges that may affect electricity service continuity. Thus, examining maintenance implementation in relation to service reliability and downtime mitigation can provide a basis for identifying improvements in electric cooperative operations.

Foreign studies generally show that maintenance practices and electrical-service reliability are closely connected, though they examine the relationship through different technical

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approaches. Ravaghi Ardabili et al. (2021) demonstrated a reliability-centered maintenance (RCM) approach for electrical distribution networks, linking maintenance decisions with reliability performance. Enjavimadar and Rastegar (2022) likewise showed that RCM can prioritize failure modes while considering outage, maintenance, safety, and operational costs. Bandara et al. (2023) emphasized that condition assessment and inspection technologies are important for managing aging distribution infrastructure and reducing failure risks. Wang et al. (2023) further showed that condition-based maintenance policies for electrical distribution systems can use inspection and failure information to improve maintenance decisions. Ghasemi et al. (2023) reviewed equipment-failure estimation in power distribution networks and highlighted the importance of degradation, diagnosis, prognostics, and maintenance information. Taken together, these studies indicate that maintenance contributes to reliability not through one activity alone but through a combination of prevention, inspection, condition assessment, planning, and timely intervention.

In the Philippine setting, electricity reliability remains an important concern because interruptions are influenced by environmental, technical, and supply-related factors. Francisco (2022) and Philippine Institute for Development Studies (PIDS, 2023) found that these factors contribute to differences in interruption frequency and service performance among electric cooperatives, while Francisco and Abrigo (2024) showed that prolonged interruptions can disrupt local economic activities and public services. The Energy Regulatory Commission (ERC, 2013) established reliability standards using indicators such as System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI), while the National Electrification Administration (NEA, 2024) emphasized maintenance activities such as transformer testing, inspections, thermal scanning, and power-quality assessment to support reliable distribution systems. Recent evidence from David et al. (2025) also suggests that preventive maintenance can improve distribution-system performance. Taken together, these studies indicate that service reliability is closely associated with technical conditions, maintenance practices, and operational planning; however, research still needs to examine how the broader implementation of maintenance operations relates to service reliability and downtime mitigation among electric cooperatives, particularly in Negros Occidental, Philippines.

Despite these studies and institutional references, a research gap remains concerning the relationship between the broader implementation of maintenance operations and perceived service reliability and downtime mitigation within the selected electric cooperative. Foreign studies examined technical approaches to maintenance prioritization through reliability modeling and expenditure allocation (Ravaghi Ardabili et al., 2021) and equipment risk assessment and maintenance strategy selection (Enjavimadar & Rastegar, 2022). In the Philippine setting, Francisco (2022) and PIDS (2023) discussed factors affecting interruptions and cooperative performance, while Francisco and Abrigo (2024) examined the consequences of prolonged interruptions for economic activities and public services. Escresa and Glova (2024) addressed political and economic influences on cooperative performance, and David et al. (2025) provided evidence concerning preventive maintenance and distribution-system performance. Meanwhile, the ERC established reliability performance standards, and the NEA (2024) emphasized technical maintenance activities that support reliable distribution systems. Although these sources offer relevant evidence and guidance, the reviewed literature does not sufficiently explain how the combined implementation of preventive maintenance, corrective maintenance, predictive or condition-based maintenance, inspection and monitoring, planning and scheduling, and resource and personnel management relates to personnel's perceptions of interruption frequency, interruption duration, fault detection and response, restoration time, and continuity of electric service within the selected cooperative. Furthermore, standards and recommended maintenance activities do not establish how extensively these practices are implemented or what challenges personnel encounter in

applying them. This study therefore assessed maintenance implementation, examined its relationship with perceived service reliability and downtime mitigation, and identified operational challenges within one electric cooperative in Negros Occidental, Philippines. This assessment was needed to provide localized evidence for a proposed maintenance operations improvement framework responsive to identified maintenance needs, while recognizing that personnel perceptions do not substitute for recorded reliability performance.

The electric cooperative covered by this study serves households, businesses, and public institutions within its service area in Negros Occidental, Philippines. Its responsibilities include operating and maintaining distribution facilities, such as power lines, transformers, meters, and related equipment, as well as restoring electricity after service interruptions. A recurring maintenance challenge is the frequent need to clear vegetation near distribution lines. Addressing this concern requires regular inspection, appropriate scheduling, sufficient personnel, suitable equipment, and coordination among responsible units. Delays in clearing vegetation may expose distribution facilities to faults and interruptions, creating additional demands for corrective maintenance and service restoration. These recurring operational needs made the present study timely and relevant by highlighting the need for evidence to guide maintenance planning and resource allocation. By assessing maintenance implementation, its relationship with personnel's perceptions of service reliability and downtime mitigation, and the challenges encountered, the study provided a basis for identifying practices to sustain and weaknesses requiring attention. Its practical contribution lies in informing decisions on line-clearing priorities, inspection schedules, personnel deployment, equipment availability, and coordination of fault response and restoration activities. These findings informed a proposed maintenance operations improvement framework to guide cooperative management in organizing maintenance activities and prioritizing improvements based on identified needs. Evaluating these improvements through interruption and restoration records can help the cooperative determine whether subsequent maintenance actions contribute to measurable improvements in service reliability and downtime mitigation.

The study aimed to assess the implementation of maintenance operations and determine their relationship with perceived service reliability and downtime mitigation within one electric cooperative in Negros Occidental, Philippines. Specifically, it assessed six dimensions of maintenance operations: preventive maintenance, corrective maintenance, predictive or condition-based maintenance, inspection and monitoring, maintenance planning and scheduling, and resource and personnel management. It also determined perceived service reliability and downtime mitigation in terms of interruption frequency, interruption duration, fault detection and response, restoration time, and continuity of electric service. Furthermore, the study examined whether a statistically significant relationship existed between the variables and identified the major problems and challenges encountered in implementing maintenance operations. The findings served as the basis for developing a proposed maintenance operations improvement framework. Anchored on the RCM framework, the study contributed context-specific evidence on the association between maintenance implementation and perceived service outcomes, interpreted through RCM principles. Its theoretical contribution lies in examining the relevance of these principles to maintenance practices within a local electric cooperative, without claiming to establish causal relationships or validate the entire RCM framework. Its practical contribution is to provide evidence to guide maintenance planning, resource allocation, personnel coordination, and prioritizing operational improvements. The proposed framework provides a structured basis for addressing identified maintenance challenges and guiding actions to strengthen service reliability and reduce downtime.

## LITERATURE REVIEW

This section presents relevant literature and studies related to maintenance operations, service reliability, and downtime mitigation. It provides the theoretical and empirical basis for examining the relationship between maintenance practices and electric service reliability

### Reliability-Centered Maintenance (RCM) Framework

The study was anchored in the RCM framework, a systematic approach that supports selecting maintenance activities based on equipment failures and their effects on operational reliability. Wang et al. (2023) explained this approach through a framework that uses fault-tree analysis to evaluate equipment failures and the effects of maintenance actions in distribution grids. Their framework supports selecting and prioritizing preventive maintenance for transformers, switchgear panels, and power cables. Ravaghi Ardabili et al. (2021) developed a probabilistic RCM framework approach for electrical distribution networks. Their approach assessed component reliability and guided preventive maintenance budget allocation while considering customer outage costs and financial constraints. Similarly, Enjavimadar and Rastegar (2022) applied failure modes and effects analysis to prioritize equipment risks and identify maintenance strategies that consider maintenance, outage, and safety costs.

Taken together, the reviewed literature suggested that maintenance effectiveness depends on coordinating technical activities with planning and resource management. This perspective complements the International Organization for Standardization's (ISO, 2024) emphasis on managing assets throughout their life cycles to support organizational objectives. The present study was anchored on the RCM framework because its focus on preserving equipment functions and addressing failure consequences was relevant to sustaining reliable electricity service. Preventive maintenance, predictive or condition-based maintenance, and inspection and monitoring support failure prevention and early defect detection, while corrective maintenance restores equipment function. Planning and scheduling, together with resource and personnel management, support the implementation of these activities. Within the selected electric cooperative in Negros Occidental, recurring line-clearing needs illustrate this coordination: inspections identify vegetation hazards, planning establishes priorities and schedules, and resource management ensures that crews and equipment are available. These operational needs highlight the importance of examining maintenance practices within the cooperative's local conditions. RCM framework therefore provided a basis for assessing the six maintenance dimensions together and examining their relationship with personnel's perceptions of service reliability and downtime mitigation. Its principles also guided the proposed Maintenance Operations Improvement Framework by emphasizing equipment condition, failure consequences, and maintenance priorities.

### Service Reliability and Downtime Mitigation

Service reliability and downtime mitigation were the study's second variable and refer to an electric cooperative's ability to provide continuous, dependable electricity while minimizing service interruptions and restoring power efficiently when failures occur. In the Philippine setting, ERC Resolution No. 01, Series of 2013 established reliability-index standards for on-grid electric cooperatives, particularly measures related to interruption frequency and duration. Francisco (2022) identified environmental, supply, and technical factors associated with electricity interruptions, while Francisco and Abrigo (2024) found that power interruptions can result in economic disruptions. Escresa and Glova (2024) emphasized the important role of electric cooperatives in providing reliable electricity to rural communities. Similarly, NEA (2024) reported technical-performance assessment activities involving reliability indicators, voltage conditions,

loading, and system losses. These regulatory provisions and studies highlighted the importance of reliable electricity service, effective responses to system failures, and minimizing service downtime in electric cooperative operations.

In the context of the selected electric cooperative, service reliability and downtime mitigation are assessed through five dimensions: interruption frequency, interruption duration, fault detection and response, restoration time, and continuity of electric service. Interruption frequency refers to how often customers experience power interruptions, while interruption duration refers to how long electricity service remains interrupted. These two dimensions directly measure the occurrence and extent of service disruptions. Fault detection and response refer to the cooperative's ability to identify system problems and respond promptly to reported or detected faults. Restoration time measures how efficiently and promptly the cooperative restores service after an interruption. Finally, continuity of electric service reflects the cooperative's ability to provide dependable electricity with minimal and manageable disruptions.

Taken together, these five dimensions provide a comprehensive basis for assessing service reliability and downtime mitigation in the selected electric cooperative. They cover both the extent of service interruptions and the cooperative's capacity to detect faults, respond to problems, restore service, and maintain continuity of electricity supply. These dimensions are therefore appropriate for examining the relationship between service reliability and downtime mitigation, as well as the implementation of maintenance operations.

**Relationship Between Maintenance Operations and Service Reliability and Downtime Mitigation**

The reviewed literature supports a relationship between maintenance operations and service reliability by explaining how maintenance decisions influence equipment failures and service interruptions. Ravaghi Ardabili et al. (2021) developed a probabilistic RCM framework approach that linked component reliability with preventive and corrective maintenance decisions and budget allocation. Their model connected maintenance priorities with customer outage costs and resource constraints, supporting the view that appropriately targeted maintenance can improve distribution-system reliability. This provides a technical basis for expecting effective maintenance planning and resource allocation to reduce equipment-related interruptions.

Similarly, Wang et al. (2023) developed fault-tree models for transformers, switchgear panels, and power cables to evaluate how failures and maintenance actions influence equipment reliability. Their framework estimated the effects of maintenance strategies on reliability indicators and supported the selection and prioritization of preventive maintenance. This establishes a modeled link between maintenance actions and equipment reliability, which is relevant to maintaining continuity of electricity service. Enjavimadar and Rastegar (2022) also examined maintenance strategy selection through equipment risk assessment, considering maintenance, outage, and safety costs. Together, these studies indicate that the relationship involves both the suitability of technical maintenance actions and the prioritization of available resources.

Applied to the present study, these perspectives suggest that preventive maintenance, condition-based maintenance, and inspection may support lower interruption frequency by addressing deterioration and detecting developing defects. Corrective maintenance, supported by appropriate scheduling, available personnel, equipment, and materials, may facilitate fault response and restoration, thereby limiting interruption duration. For the selected electric cooperative in Negros Occidental, recurring line-clearing needs illustrate these connections: inspections identify vegetation hazards, scheduled clearing addresses potential fault sources, and crew and equipment availability support timely action. These are proposed operational links that explain why maintenance implementation may be associated with perceived service reliability and

downtime mitigation.

Overall, the literature supports the expectation that more effective maintenance implementation is associated with better service reliability and downtime mitigation. However, the cited technical models do not establish the strength or statistical significance of the relationship between personnel assessments within the selected cooperative. The present study therefore examined whether higher maintenance implementation ratings were associated with more favorable ratings of interruption frequency, interruption duration, fault detection and response, restoration time, and continuity of electric service. Consistent with its descriptive-correlational design, the study assessed association without establishing causation.

The reviewed literature provides a basis for expecting an association between maintenance implementation and service reliability and downtime mitigation, as it links maintenance decisions with equipment reliability and interruption-related consequences. Accordingly, the study formulated the following alternative hypothesis:

$H_a$: There is a statistically significant relationship between the extent of implementation of maintenance operations and the perceived level of service reliability and downtime mitigation in the selected electric cooperative in Negros Occidental, Philippines.

This hypothesis was evaluated using Spearman's rank-order correlation at the predetermined significance level to determine whether the respondents' assessments provided sufficient evidence of an association between the variables. Consistent with the descriptive-correlational design, the analysis examined association without establishing causation.

**Challenges Encountered in the Implementation of Maintenance Operations**

Maintenance operations in electric distribution systems face technical, financial, and organizational challenges. Aging assets require careful assessment of deterioration and maintenance or replacement needs (Shaghaghi et al., 2024), while budget limitations require utilities to balance maintenance priorities with reliability requirements (Ravaghi Ardabili et al., 2021). Adopting monitoring technologies also presents challenges related to data requirements, implementation uncertainty, and unclear investment returns (Mortensen et al., 2024). Furthermore, technical-economic and organizational barriers can hinder the digitalization of asset management (Monaco et al., 2024). These studies provide a basis for examining how equipment condition, funding, maintenance information, and technology adoption constrain maintenance implementation within the selected electric cooperative.

Taken together, the reviewed literature indicates that maintenance challenges involve interconnected equipment, financial, technological, and organizational concerns. Aging assets increase maintenance and replacement demands (Shaghaghi et al., 2024), while budget constraints affect maintenance priorities and resource allocation (Ravaghi Ardabili et al., 2021). Data requirements, uncertain investment returns, and organizational barriers further complicate the adoption of advanced monitoring and maintenance systems (Mortensen et al., 2024). These concerns complement NEA's (2024) emphasis on improving technical and operational performance in Philippine electric cooperatives. They suggest that addressing equipment problems also requires adequate resources, reliable information, and coordinated implementation. Guided by this synthesis, the present study examined personnel and training needs, tools and spare parts, budget limitations, scheduling difficulties, aging facilities, monitoring technologies, and response delays within the selected cooperative. Assessing these challenges provided a basis for prioritizing actions in the proposed Maintenance Operations Improvement Framework according to identified operational needs.

## RESEARCH METHOD

This study used a quantitative descriptive-correlational research design to describe maintenance implementation, perceived service reliability and downtime mitigation, and maintenance challenges, and to examine relationships among the principal variables without manipulating them (Miksza et al., 2023). The subject electric cooperative serves households, businesses, and public institutions within its service area in Negros Occidental, Philippines. It operates and maintains distribution facilities, including power lines, transformers, and meters, and restores electricity following interruptions. Recurring activities, such as line clearing, require coordination among technical and administrative personnel. The eligible population consisted of 130 qualified personnel from Maintenance, Line Operations, Engineering, Substation Operations, Technical Services, and Office/Administrative Services. Eligibility depended on responsibilities involving direct maintenance activities or relevant support functions, rather than job designation alone. Maintenance and line operations personnel performed inspections, line clearing, repairs, and restoration. In contrast, engineering, substation operations, and technical services personnel contributed knowledge of equipment condition, system performance, maintenance planning, and fault response. Office and administrative personnel were eligible when their duties involved maintenance records, procurement, budgeting, personnel coordination, or service-related documentation. Using simple random sampling, 98 respondents were selected, giving each eligible employee an equal chance of selection and representing approximately 75.4% of the eligible population. The sample-size adequacy was assessed using a finite-population calculation with a 95% confidence level, a 5% margin of error, and a 50% response distribution. These parameters yielded a minimum sample of 98 respondents after rounding upward, indicating that the achieved sample met the specified precision requirement for estimating population proportions under simple random sampling (Lakens, 2022).

The researchers collected data using a structured questionnaire with four parts. Part I gathered respondents' work unit, position or designation, and years of experience within the cooperative. Part II contained 21 statements covering preventive maintenance, corrective maintenance, predictive or condition-based maintenance, inspection and monitoring, maintenance planning and scheduling, and resource and personnel management. Part III contained 12 statements assessing perceived interruption frequency, interruption duration, speed of fault detection and response, restoration time, and continuity and reliability of electric service. Part IV included nine statements addressing maintenance challenges. The survey used five-point scales with section-specific labels. Part II used 1—Not Implemented, 2—Slightly Implemented, 3—Moderately Implemented, 4—Highly Implemented, and 5—Very Highly Implemented. Its mean-score interpretation ranges were 1.00–1.80, 1.81–2.60, 2.61–3.40, 3.41–4.20, and 4.21–5.00, respectively. Part III used 1—Strongly Disagree, 2—Disagree, 3—Neither Agree nor Disagree, 4—Agree, and 5—Strongly Agree. Part IV used 1—Not a Challenge, 2—Minor Challenge, 3—Moderate Challenge, 4—Serious Challenge, and 5—Very Serious Challenge. Instrument development drew on maintenance and reliability literature (Ravaghi Ardabili et al., 2021) and asset management principles (ISO, 2024). Three validators with relevant expertise reviewed the questionnaire for relevance, clarity, appropriateness, and alignment with the research objectives, consistent with expert-review recommendations discussed by Kishore et al. (2021)—their feedback guided revisions to the wording, instructions, scales, and technical coverage. The revised questionnaire was pilot-tested with 10 qualified personnel from the same cooperative whose work characteristics were similar to those of the target respondents and who were excluded from the actual sample of 98. The statistician assessed internal consistency using Cronbach's alpha, adopting 0.70 as the minimum acceptable coefficient. Table 1 presents coefficients ranging from 0.777 to 0.994 for maintenance operations and from 0.710 to 0.872 for perceived service reliability and downtime

mitigation, and 0.948 for maintenance challenges. All reported coefficients exceeded the adopted threshold, consistent with Kishore et al. (2021), who identified Cronbach's alpha values above 0.70 as preferred for internal consistency.

**Table 1.** Reliability Statistics

| Dimension | No. of Items | Cronbach's Alpha |
|---|---|---|
| **Implementation of Maintenance Operations** | | |
| Preventive maintenance | 5 | .994 |
| Corrective maintenance | 3 | .892 |
| Predictive or condition-based maintenance | 3 | .892 |
| Inspection and monitoring | 3 | .892 |
| Maintenance planning and scheduling | 4 | .931 |
| Resource and personnel management | 3 | .777 |
| **Service Reliability and Downtime Mitigation** | | |
| Frequency of power interruptions | 2 | .713 |
| Duration of power interruptions | 2 | .734 |
| Speed of fault detection and response | 2 | .710 |
| Restoration time | 2 | .872 |
| Continuity and reliability of electric service | 3 | .760 |
| **Challenges Encountered in the Implementation of Maintenance Operations** | 9 | .948 |

Researchers distributed printed questionnaires to 98 respondents from September 21 to 24, 2026, along with verbal instructions explaining the study's purpose and how to complete each section. Respondents were instructed to answer based on their actual work experience and observations. The researchers obtained permission from the cooperative and informed consent from the respondents before participation. Participation was voluntary, and respondents could decline or withdraw without penalty. Names were not required, responses were treated confidentially and used solely for academic purposes, and findings were reported in aggregate form to protect individual identities. The collected data were organized, encoded, and submitted to a statistician for analysis in line with the research objectives. Frequencies and percentages summarized respondents' work units, positions or designations, and years of experience, while weighted means described maintenance implementation, perceived service reliability and downtime mitigation, and maintenance challenges using the corresponding interpretation scales. The Shapiro–Wilk test assessed the normality of the two principal variables. Maintenance implementation scores showed a statistically significant departure from normality, supporting Spearman's rank-order correlation to examine the direction and strength of their association with perceived service reliability and downtime mitigation. Hypothesis testing used a significance level of .05. Findings were presented in tables and interpreted according to the research objectives, recognizing that the descriptive-correlational design examined associations between variables without establishing causation (Janse et al., 2021).

## FINDINGS AND DISCUSSION

Following data collection, this section presents, analyzes, and interprets the data obtained through the survey questionnaire to address the study's objectives.

### Demographic Profile of Respondents

Table 2 presents the demographic profile of the 98 respondents by area of assignment or work unit, position or designation, and years of experience in the electric cooperative.

**Table 2.** Demographic Profile of the Respondents

| Profile Variable | Category | Frequency (f) | Percentage (%) |
|---|---|---|---|
| **Area of Assignment/Work Unit** | Maintenance | 22 | 22.45 |
| | Line Operations | 38 | 38.78 |
| | Engineering | 9 | 9.18 |
| | Substation Operations | 2 | 2.04 |
| | Technical Services | 14 | 14.29 |
| | Office/Administrative Services | 13 | 13.27 |
| | **Total** | **98** | **100.00** |
| **Position/ Designation** | Manager/Supervisor | 8 | 8.16 |
| | Engineer | 6 | 6.12 |
| | Foreman/Team Leader | 7 | 7.14 |
| | Lineman/Field Personnel | 60 | 61.22 |
| | Technician | 7 | 7.14 |
| | Office Personnel | 10 | 10.20 |
| | **Total** | **98** | **100.00** |
| **Years of Experience in the Electric Cooperative** | Less than 1 year | 5 | 5.10 |
| | 1–5 years | 21 | 21.43 |
| | 6–10 years | 36 | 36.73 |
| | 11–15 years | 19 | 19.39 |
| | More than 15 years | 17 | 17.35 |
| | **Total** | **98** | **100.00** |

Table 2 shows that most respondents were assigned to Line Operations (38.78%) and Maintenance (22.45%), while linemen and field personnel made up the majority by position (61.22%). This indicates that the findings primarily reflected the perspectives of personnel directly involved in maintaining distribution facilities and responding to service interruptions. Respondents from engineering, technical, substation, and administrative services contributed additional perspectives on maintenance planning, coordination, and support. Regarding length of service, the largest group had 6–10 years of experience (36.73%), and 73.47% had served for at least six years, suggesting sustained exposure to the cooperative's maintenance practices and recurring operational concerns. This interpretation is aligned with the International Organization

for Standardization (ISO, 2024), which emphasizes personnel involvement, knowledge, awareness, and team interdependence in implementing asset management activities. Overall, the profile suggests that the assessments were largely informed by experienced operational personnel, although length of service alone did not establish technical competence.

**Extent of Implementation of Maintenance Operations**

Maintenance operations involve coordinated activities to assess equipment condition, address faults, and organize resources. Ravaghi Ardabili et al. (2021) linked maintenance allocation to component reliability, outage costs, and budget constraints, providing a basis for examining these practices within the cooperative. Table 3 presents the respondents' assessments of maintenance implementation across the six dimensions.

**Table 3.** Extent of Implementation of Maintenance Operations

| Dimension | Mean | Interpretation |
|---|---|---|
| Preventive Maintenance | 4.29 | Very Highly Implemented |
| Corrective Maintenance | 4.33 | Very Highly Implemented |
| Predictive or Condition-Based Maintenance | 4.23 | Very Highly Implemented |
| Inspection and Monitoring | 4.25 | Very Highly Implemented |
| Maintenance Planning and Scheduling | 4.35 | Very Highly Implemented |
| Resource and Personnel Management | 4.33 | Very Highly Implemented |
| **Composite Mean** | **4.30** | **Very Highly Implemented** |

Table 3 shows that maintenance operations were perceived as very highly implemented across all six dimensions, with a composite mean of 4.30. Maintenance Planning and Scheduling obtained the highest mean (4.35), followed by Corrective Maintenance and Resource and Personnel Management (both 4.33), Preventive Maintenance (4.29), Inspection and Monitoring (4.25), and Predictive or Condition-Based Maintenance (4.23). These ratings suggest that respondents perceived maintenance as an established and coordinated part of the cooperative's operations. Very high preventive maintenance implementation suggests the cooperative regularly carried out activities intended to prevent equipment failures. In contrast, very high corrective maintenance implementation indicates that the organization actively undertook repair activities when problems occurred. The ratings for predictive or condition-based maintenance and inspection and monitoring suggest that the organization assessed equipment conditions to identify potential defects and determine maintenance needs. Similarly, the ratings for planning and scheduling and resource and personnel management indicate that the organization organized maintenance activities and supported them with the allocation of personnel, tools, and materials. Taken together, these findings imply that the cooperative's perceived maintenance practices covered failure prevention, equipment assessment, repair, and operational support. Although predictive or condition-based maintenance received the lowest mean, it remained very highly implemented and represented a relative opportunity for further improvement.

The findings are aligned with the maintenance approach described by Ravaghi Ardabili et al. (2021), who evaluated component reliability to prioritize preventive maintenance resource allocation and balance preventive and corrective maintenance activities in electrical distribution networks. In particular, the high ratings for planning and scheduling and resource and personnel management align with the literature's emphasis on organizing maintenance priorities and

allocating resources based on reliability needs. The very high ratings for preventive and corrective maintenance likewise reflect the complementary maintenance activities emphasized in their approach. Furthermore, the favorable assessments of inspection, monitoring, and condition-based maintenance suggest practices that could provide equipment-condition information for reliability-based decisions. These findings support the relevance of the RCM framework to interpreting the cooperative's maintenance practices, although the survey ratings alone do not demonstrate actual reductions in interruptions. Practically, the cooperative should sustain its coordinated maintenance practices and better use inspection findings, equipment-condition records, and diagnostic information to guide maintenance priorities and resource allocation.

**Perceived Service Reliability and Effectiveness of Downtime Mitigation**

This section presents respondents' assessment of electric service continuity and the cooperative's handling of power interruptions. The assessment covers five dimensions: frequency of power interruptions; duration of power interruptions; speed of fault detection and response; restoration time; and continuity and reliability of electric service. Table 4 summarizes perceived service reliability and the effectiveness of downtime mitigation across these dimensions.

**Table 4.** Perceived Service Reliability and Downtime Mitigation

| Dimension | Mean | Interpretation |
|---|---|---|
| Frequency of Power Interruptions | 4.12 | High |
| Duration of Power Interruptions | 4.19 | High |
| Speed of Fault Detection and Response | 4.17 | High |
| Restoration Time | 4.33 | Very High |
| Continuity and Reliability of Electric Service | 4.32 | Very High |
| **Composite Mean** | **4.23** | **Very High** |

Table 4 shows that respondents perceived service reliability and the effectiveness of downtime mitigation as very high, with a composite mean of 4.23. Restoration Time obtained the highest mean (4.33), closely followed by Continuity and Reliability of Electric Service (4.32), both interpreted as very high. These findings imply that respondents viewed the cooperative as highly capable of restoring electricity following interruptions and maintaining dependable service. Respondents also rated Duration of Power Interruptions (4.19), Speed of Fault Detection and Response (4.17), and Frequency of Power Interruptions (4.12) highly. The high rating for interruption duration suggests respondents perceived the cooperative as generally effective at limiting outage length. Similarly, the rating for fault detection and response indicates that personnel were perceived as capable of identifying faults and initiating appropriate action promptly. The high rating for interruption frequency reflects a favorable assessment of efforts to minimize recurring interruptions; it does not mean that interruptions occurred frequently. Taken together, the findings suggest that respondents viewed the cooperative's outage management favorably, with restoration and service continuity as strengths. The relatively lower ratings for interruption frequency, duration, and initial fault response indicate areas where further improvements could strengthen overall service performance.

The findings are aligned with the RCM approach of Ravaghi Ardabili et al. (2021), which emphasized evaluating component reliability, prioritizing preventive maintenance resources, and balancing preventive and corrective maintenance activities in electrical distribution networks. The favorable assessments of interruption frequency and duration align with this approach's

preventive emphasis, which addresses equipment risks that can cause service disruptions. Meanwhile, the favorable ratings for fault detection, response, and restoration are consistent with the complementary role of corrective maintenance in addressing failures and returning facilities to service. The very high assessment of service continuity reflects the broader reliability objective supported by this combination of maintenance activities. Thus, the literature supports the view that coordinated preventive and corrective practices support dependable electricity service and reduce downtime. Within the study's RCM framework, the cooperative should sustain its restoration capabilities while using recurring fault reports and equipment-condition records to strengthen interruption prevention and initial response. However, the findings represent personnel perceptions; actual outage records are needed to verify interruption frequency, duration, and restoration performance.

**Relationship Between Maintenance Operations and Service Reliability and Downtime Mitigation**

The study examined whether maintenance implementation was significantly related to perceived service reliability and downtime mitigation. It tested the alternative hypothesis ($H_a$): There is a statistically significant relationship between the extent of implementation of maintenance operations and the perceived level of service reliability and downtime mitigation in the selected electric cooperative in Negros Occidental, Philippines. Before testing this relationship, the Shapiro–Wilk test was used at the .05 significance level to assess the normality of the scores and help guide the choice of correlation test. Kamath et al. (2025) supported its use in detecting departures from normality. A p-value below .05 indicated a significant departure from normality, while a p-value above .05 indicated no significant departure. Table 5 presents the normality test results for the two variables.

**Table 5.** Shapiro–Wilk Test of Normality

| Variable | W | p-value | Interpretation |
|---|---|---|---|
| Implementation of Maintenance Operations | 0.950 | 0.001 | Significant departure from normality |
| Service Reliability and Effectiveness of Downtime Mitigation | 0.978 | 0.092 | No significant departure from normality |

*Note. N = 98; W = Shapiro–Wilk statistic; α = .05. Maintenance implementation scores departed from normality (p = .001), supporting the use of Spearman's rank-order correlation to examine the relationship between the variables.*

Table 5 shows that maintenance implementation scores departed significantly from normality (W = .950, p = .001), while perceived service reliability and downtime mitigation effectiveness scores showed no significant departure (W = .978, p = .092). These findings supported using Spearman's rank-order correlation to examine relationships because it does not require normally distributed scores. The normality assessment guided the choice of statistical test. Table 6 presents the strength, direction, and statistical significance of the relationship between maintenance implementation and perceived service reliability and downtime mitigation.

**Table 6.** Relationship Between Maintenance Operations and Service Reliability and Downtime Mitigation

| Variables Correlated | Spearman's $r_s$ | p-value | Interpretation | Decision on $H_a$ |
|---|---|---|---|---|
| Implementation of Maintenance Operations and Service Reliability and Effectiveness of Downtime Mitigation | 0.764 | < .001 | Strong positive relationship | Accepted |

Table 6 shows a strong, statistically significant positive relationship between maintenance implementation and perceived service reliability and downtime-mitigation effectiveness ($r_s = .764$, $p < .001$). Since the p-value was below the .05 significance level, the alternative hypothesis ($H_a$) was accepted. Respondents who rated maintenance implementation more favorably also tended to report better service reliability and more effective downtime mitigation. This implies that more extensive maintenance implementation was associated with perceptions of fewer and shorter interruptions, faster fault response and restoration, and more continuous electricity service. However, the correlation concerned the overall scores and did not establish separate relationships for each dimension or identify which maintenance practice contributed most. Consistent with Janse et al. (2021), the significant association did not establish that maintenance implementation caused better service outcomes.

This finding aligns with the study's RCM framework because the observed association matches its emphasis on maintaining equipment reliability through appropriate maintenance decisions. Ravaghi Ardabili et al. (2021) supported this connection by evaluating component reliability to prioritize preventive maintenance resources and balance preventive and corrective activities in electrical distribution networks. Their approach shows why directing inspections, repairs, and resources toward equipment with greater reliability matters for service continuity. This finding aligns with this principle, though it reflects personnel perceptions rather than measured equipment performance. For the cooperative, this suggests using equipment-condition assessments, recurring fault records, and maintenance work orders to guide priorities. Actual interruption and restoration records are needed to determine whether these practices corresponded with measurable improvements in reliability and downtime.

The strong positive relationship between maintenance implementation and perceived service reliability and downtime mitigation aligns with the study's RCM framework, which emphasizes directing maintenance activities toward equipment reliability and the consequences of failure. This interpretation is aligned with Ravaghi Ardabili et al. (2021), whose RCM approach evaluated component reliability to prioritize preventive maintenance resources and balance preventive and corrective activities in electrical distribution networks. The findings suggest that personnel who perceived maintenance practices as more extensively implemented also reported more favorable service outcomes, supporting RCM's relevance as an interpretive framework. Practically, the cooperative could strengthen this alignment by using equipment-condition assessments and recurring fault records to guide maintenance priorities. However, the association reflected personnel perceptions and did not independently validate the framework or demonstrate actual reductions in downtime.

**Challenges Encountered in Implementing Maintenance Operations**

This section presents the challenges personnel encountered in implementing maintenance operations within the electric cooperative. These include concerns related to aging facilities, monitoring technology, fault response, resources, personnel, training, and maintenance schedules. Table 7 summarizes the respondents' assessment of the severity of these challenges using mean scores and their corresponding interpretations.

**Table 7.** Challenges Encountered in Implementing Maintenance Operations

| Challenges | Mean | Interpretation |
|---|---|---|
| Aging electrical distribution facilities and equipment | 3.05 | Moderate |
| Limited availability of advanced monitoring and diagnostic technologies | 3.03 | Moderate |
| Delays in responding to equipment failures | 2.92 | Moderate |
| Limited budget for maintenance activities | 2.90 | Moderate |
| Inadequate maintenance tools and equipment | 2.88 | Moderate |
| Insufficient maintenance personnel | 2.87 | Moderate |
| Limited availability of spare parts and materials | 2.87 | Moderate |
| Limited specialized training and technical skills | 2.85 | Moderate |
| Difficulty in consistently following maintenance schedules | 2.80 | Moderate |
| **Composite Mean** | **2.91** | **Moderate** |

Table 7 shows that all nine challenges in implementing maintenance operations received moderate ratings, with mean scores ranging from 2.80 to 3.05. Aging electrical distribution facilities and equipment received the highest mean (3.05), followed by limited availability of advanced monitoring and diagnostic technologies (3.03) and delays in responding to equipment failures (2.92); the remaining challenges concerned budgets, tools, personnel, spare parts, training, and maintenance schedules. The moderate ratings imply that respondents viewed these concerns as meaningful difficulties that could hinder maintenance activities and required attention. However, they were not generally assessed as serious or very serious. Equipment condition and monitoring capabilities emerged as the leading concerns based on their mean scores, but the small differences were descriptive and did not establish significant differences in severity. Alongside the very high maintenance implementation ratings, these findings suggest that established maintenance practices coexisted with resource and operational limitations. The cooperative should therefore address these constraints to sustain maintenance implementation and prevent them from worsening. However, the moderate overall assessments did not rule out greater difficulties experienced by individual personnel.

The findings align with the maintenance priorities emphasized by Enjavimadar and Rastegar (2022), who considered failure risks alongside maintenance, outage, and safety costs when selecting maintenance strategies. The reported challenges involving aging equipment, limited monitoring technologies, and response delays suggest a need to identify equipment problems early and prioritize actions according to their potential consequences. Similarly, concerns about budgets, personnel, tools, and spare parts highlight the importance of considering available resources when planning maintenance. The cited study therefore supports addressing these challenges through risk-based maintenance decisions, although it does not directly confirm their moderate severity in the cooperative. In relation to the RCM framework, the findings suggest that the cooperative should

use equipment-condition assessments and failure histories to identify critical facilities requiring monitoring, repair, or replacement and allocate resources accordingly.

**Proposed Maintenance Operations Improvement Framework**

The proposed maintenance operations improvement framework was based on the study's findings and followed RCM principles. It drew on the very high maintenance implementation ratings, the high-to-very-high perceived service outcomes, the significant positive relationship between these variables, and the moderate maintenance challenges. Particular attention focused on the relatively lower ratings for predictive or condition-based maintenance and interruption frequency, along with concerns about aging equipment, limited monitoring technologies, and response delays. The framework aims to sustain established practices and address these identified areas through maintenance priorities informed by equipment condition and failure consequences. Table 8 presents the improvement areas, proposed actions, responsible functions, and monitoring indicators. Its effectiveness depends on implementation and evaluation using operational records.

**Table 8.** Proposed Maintenance Operations Improvement Framework

| Maintenance Dimension | Findings and Improvement Areas | Proposed Actions | Responsible Functions | Monitoring Indicators |
|---|---|---|---|---|
| **Preventive Maintenance** | Preventive maintenance was implemented very well, while aging facilities remained a moderate challenge. Prioritize assessment and servicing of deteriorating distribution assets. | Use condition and fault history to prioritize servicing, line clearing, and asset assessment. | Maintenance; Line Operations; Engineering | Tasks completed; repeat faults; defects resolved |
| **Corrective Maintenance** | Corrective maintenance was implemented very well, but response delays remained a moderate challenge. Strengthen fault reporting, crew dispatch, and repair coordination. | Review reporting and dispatch; track repair times and address recurring delays. | Maintenance; Line Operations; Substation Operations; Technical Services | Dispatch and restoration times; repeat failures |
| **Predictive or Condition-Based Maintenance** | Condition-based maintenance had the lowest relative implementation rating. Limited diagnostic technology was a moderate challenge. Improve access to diagnostic tools and condition information. | Assess diagnostic needs; phase in monitoring tools; link condition alerts to work orders. | Engineering; Technical Services; Substation Operations; Procurement | Assets monitored; alerts investigated; work orders completed |

| Maintenance Dimension | Findings and Improvement Areas | Proposed Actions | Responsible Functions | Monitoring Indicators |
|---|---|---|---|---|
| **Inspection and Monitoring** | Inspection and monitoring were implemented very well, while fault detection and response were rated high. Link inspection findings to timely defect correction. | Standardize inspection records; assign defect urgency, owners, and due dates; track closure. | Maintenance; Line Operations; Substation Operations; Technical Services | Inspections completed; overdue defects; time to action |
| **Maintenance Planning and Scheduling** | Planning and scheduling had the highest implementation rating, while schedule difficulties remained moderate. Improve completion of scheduled work and follow up on deferred tasks. | Match schedules to resources; record deferrals; reschedule unfinished work by risk. | Maintenance Planning; Engineering; Line Operations; Administration | Schedule completion; overdue tasks; deferral reasons |
| **Resource and Personnel Management** | Resource management was implemented very well, but budgets, tools, staffing, spares, and training remained moderate challenges. Match resources and personnel support to maintenance priorities. | Align budgets and crews with priorities; maintain critical spares and tools; provide targeted training. | Management; Maintenance Supervisors; Finance; Procurement; Personnel Administration | Resource delays; stockouts; tool and staff availability; training completed |

*Note: The electric cooperative shall establish baselines and targets before implementation. The proposed framework has not yet been implemented or evaluated.*

The proposed framework presents a strategic approach to enhancing maintenance operations across six critical dimensions: preventive maintenance; corrective maintenance; predictive or condition-based maintenance; inspection and monitoring; maintenance planning and scheduling; and resource and personnel management. Each dimension connects to the study's findings to targeted improvement areas, actionable steps, assigned responsibilities, and measurable monitoring indicators. This framework underscores the importance of leveraging equipment condition and recurring fault data to prioritize maintenance efforts while optimizing available resources. This methodology aligns with Enjavimadar and Rastegar (2022), who highlighted the importance of considering failure risks, maintenance costs, outage costs, and safety expenses when selecting effective maintenance strategies for power distribution systems.

To begin implementation, conduct a thorough review of maintenance and outage records to establish baseline performance for the identified indicators. The cooperative can then tailor responsibilities to its unique organizational structure, set realistic targets, and regularly assess task completion, unresolved issues, response times, and resource-related delays. These assessments

will help refine maintenance schedules, strengthen monitoring, streamline procurement, and advance personnel development. While this framework supports timely maintenance and improves service reliability, its practicality and effectiveness must be evaluated through real-world implementation and ongoing monitoring, as the current study did not test the proposed actions. Embracing this framework can significantly improve maintenance operations and ultimately deliver a higher level of service. Likewise, this framework aligns with the consensus of previous studies (Rivera et al., 2023; De Ramos & Briones, 2024; Concepcion et al., 2026; Ginez et al., 2026; Capungan et al., 2026) that for an organization to sustain its commitment to providing quality services to its stakeholders, performance monitoring, and exploring opportunities for improvement are necessary.

## CONCLUSION

The study concluded that maintenance operations were implemented at a very high level within the electric cooperative in Negros Occidental, Philippines, with maintenance planning and scheduling receiving the most favorable assessment. Perceived service reliability and effectiveness of downtime mitigation were also very high, particularly in restoration time and service continuity. A strong positive and statistically significant relationship existed between maintenance implementation and perceived service outcomes, supporting the alternative hypothesis without establishing causation. Maintenance challenges were moderate overall, with aging facilities, limited monitoring and diagnostic technologies, and response delays emerging as the most prominent concerns. These findings provided the basis for a proposed maintenance operations improvement framework that linked each maintenance dimension to specific improvement areas, actions, responsibilities, and monitoring indicators.

The findings supported the relevance of the RCM framework by showing an association between maintenance implementation and favorable perceptions of service performance. The findings also highlighted that extensive maintenance activity can coexist with equipment and resource constraints, suggesting that applying the framework requires attention to asset condition, failure consequences, and resource adequacy alongside reported implementation. Practically, maintenance and engineering personnel should prioritize line clearing based on vegetation exposure and recurring fault records, assess deteriorating equipment for repair or replacement, and strengthen monitoring and follow-up of critical defects. Management should align budgets, staffing, training, tools, and spare parts with these priorities. It should also track deferred tasks, response delays, and repeat failures. The proposed framework should be piloted and evaluated against maintenance and outage records to assess feasibility and its contribution to service reliability and downtime mitigation.

## LIMITATIONS AND FUTURE RESEARCH RECOMMENDATIONS

The study was limited to one electric cooperative in Negros Occidental, Philippines; therefore, its findings may not apply to cooperatives with different operating conditions, resources, and maintenance practices. Both principal variables were measured through the same self-reported questionnaire, making the results susceptible to recall, social-desirability, and common-source bias. The assessments reflected personnel perceptions rather than independently verified service performance. Furthermore, the cross-sectional descriptive-correlational design measured the variables at one point in time and could not establish whether maintenance implementation caused improvements in reliability or downtime mitigation. The analysis also did not determine differences among work units or the separate contributions of individual maintenance dimensions. Finally, the small pilot sample limited the precision of the instrument's preliminary reliability estimates, and the proposed improvement framework remained untested.

The researchers recommend conducting studies across several electric cooperatives to assess whether the findings hold under different organizational and operating conditions. Future researchers should combine personnel surveys with outage logs, maintenance records, equipment assessments, and customer feedback to reduce reliance on a single information source and compare perceptions with actual performance. Longitudinal studies or phased maintenance interventions involving comparable feeders could clarify whether changes in maintenance practices precede improvements in service reliability. Adequately sized subgroup and dimension-level analyses could identify specific personnel groups and practices requiring targeted support, while larger-sample reliability and validity assessments could strengthen the questionnaire. Lastly, the proposed framework should be piloted using baseline measures and follow-up monitoring of implementation costs, recurring faults, interruption frequency and duration, and restoration times to determine its feasibility and effectiveness before wider adoption.

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