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Article

Industrial Maintenance Management to increase equipment availability in an electrical services company, Callao 2025

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Abstract: This study is aligned with Sustainable Development Goal 9 (Industry, Innovation and Infrastructure), as it seeks to strengthen a flexible infrastructure that promotes industry and fosters innovation. Unexpected equipment failures are a critical problem for industrial companies because they reduce machine availability, increase downtime and cause economic and operational losses. The general objective was to determine how Industrial Maintenance Management increases equipment availability in an electrical services company, Callao 2025. The research was applied, with a quantitative approach, explanatory level and a pre-experimental design. The population and sample comprised 16 weeks of maintenance-order records for the Bauker 6 kVA generator set, corresponding to the pretest (July–October 2025) and the posttest (January–April 2026); the technique was documentary analysis and the instrument a record sheet. The implementation was structured under the PDCA cycle combining corrective and preventive maintenance. Results show that availability increased by 35.42 % (from 66.70 % to 90.33 %), reliability by 21.70 % (from 78.88 % to 95.99 %), and maintainability decreased by 14.01 % (from 62.03 % to 53.34 %). The Wilcoxon test yielded a significance of 0.000, confirming that Industrial Maintenance Management significantly increases equipment availability.
Keywords: Maintenance, availability, maintainability, reliability, downtime

1. Introduction

Unforeseen machine failures represent a critical problem for industrial companies, as they directly impact equipment availability, increase downtime, and even paralyze production, with large-scale economic and operational consequences. Therefore, it is essential that organizations adopt maintenance management to mitigate this problem. Internationally, plant shutdowns and downtime often result from inadequate maintenance; Statista (2025) points out that an appropriate maintenance plan can generate savings of 8% to 12% for companies, and reports that in U.S. companies, 42.5% of the annual budget was allocated to equipment and machinery maintenance, compared to 29% planned.

At the Latin American level, maintenance services companies continue to grow due to their ability to offer improvement solutions to equipment, machines, and tools; however, lack of training and operational errors continue to cause emergency failures. At the national level, Peruvian companies dedicated to the installation of electrical panels have experienced sustained growth thanks to the modernization of their infrastructure and the quality of their services. At the regional level, Zegarra and Mendoza (2024) applied maintenance management to electric stackers and managed to improve availability by 12%.

The company under study provides installation and operation services for the Bauker 6 kVA generator set and faces a critical challenge that affects the availability and reliability of its equipment. Sudden failures generate delays in front of customers and low availability of the equipment used for the installation of electrical pump panels. To identify the causes of the problem, three quality tools were applied: the Ishikawa diagram, which identified 20 causes;

the Vester matrix, for classification; and the Pareto diagram, which revealed that 7 main causes account for about 80% of the low availability, including the absence of availability indicators, lack of training, staff fatigue and the lack of adequate control of maintenance scheduling.

Faced with this problem, the following general problem was raised: how does Industrial Maintenance Management increase the availability of equipment in an electric utility company, Callao 2025? The specific problems addressed the effect on reliability and maintainability. Consequently, the general objective was to determine how Industrial Maintenance Management increases the availability of equipment, and the specific objectives were to determine how it increases reliability and how it reduces maintainability.

1.1. Background

Various studies support the relationship between maintenance management and availability. Solórzano and Espinosa (2022), in Ecuador, increased availability from 41.42% to 91.78% through the four stages of the PHVA cycle based on the ISO 9001:2015 standard and failure criticality analysis, with support from the FMEA. Montalvo and Gonzáles (2024), in Cuba, increased the availability of a salt company from 65.7% to 87.3% (32.88% improvement) through the technological monitoring of critical equipment. Ronceros (2022), in Venezuela, increased the availability of telecommunications equipment from 73.34% to 99.66% based on the FMEA and PHVA, and Pillado and Castillo (2022), in Mexico, developed preventive maintenance to reduce breakdowns and increase the reliability of 32 machines.

At the national level, Condor and Vásquez (2024) increased the availability of a sugar company from 97.44% to 99.60%, supported by training and a spare parts control system. Becerra and Daviran (2021) improved availability from 74.6% to 89.9%, reliability from 69.8% to 87.6%, and reduced maintainability through procedure manuals and annual programming. Miran and Pari (2023) implemented a preventive maintenance plan that raised forklift availability from 64% to 91.7% and reduced repair costs from S/ 10,182.96 to S/ 3,692.06 per month. Nicho (2025), in Callao, applied preventive maintenance to heavy machinery and Medina and Vásquez (2023) improved reliability in rice machinery through machine coding and FMEA.

1.2. Theoretical bases

Industrial Maintenance Management. García (2011) defines it as the set of processes, tactics, and activities that a company implements to ensure that its infrastructure, machinery, and equipment operate efficiently, safely, and optimally, with the purpose of optimizing the availability and reliability of assets. Cárcel (2014) conceives it as the set of technical, administrative, and planning tasks aimed at ensuring that equipment operates safely, efficiently, and reliably, at the lowest possible cost and with maximum availability. Sancho (2023) structures it on four pillars that correspond to the continuous improvement cycle: plan (define what to do, with what, and when), do (execute what is planned with documented evidence), verify (measure and follow up through KPIs), and act (correct deviations and standardize improvement).

Types of maintenance. Corrective maintenance is executed after the failure occurs; it is reactive and unplanned in nature, and its main impact is the possible stoppage of production (Salas et al., 2024; Nogueira et al., 2024). Preventive maintenance, on the other hand, involves the planning and execution of scheduled tasks to prevent failures before they occur, maximizing the useful life of assets and reducing unplanned downtime (Castillo, 2021). Its benefits include the reduction of unplanned downtime by between 50% and 60%, the increase in the useful life of equipment, and the efficient use of spare parts (Pulido et al., 2024; Darmawan and Sheu, 2022).

Availability. It is the ability of a piece of equipment or system to be in operational condition and ready for use when required; it depends directly on reliability and maintainability (Vera et al., 2021; Vidaurre et al., 2022). It is calculated from the mean time between failures (FMT/MTBF) and the mean time to repair (TMR/MTTR). Recent literature confirms that availability is directly proportional to MTBF and inversely proportional to MTTR, so maintenance strategies should be aimed at reducing the frequency of failures and repair times (Cirineo Loyola et al., 2025; Castello et al., 2025). Reliability is the probability that a piece of equipment will operate without failure for a

given period, while maintainability is the probability that a faulty piece of equipment will be repaired and returned to its operational state in a specific time (Acuña, 2022; Gastón, 2022).

Table 1. Scale of availability values

Level	Values	Description
Low	Less than 90%	The equipment experiences constant breakdowns or prolonged periods of downtime.
Media	90% to 95%	The equipment works most of the time, but still suffers from reducible interruptions.
High	Greater than 95%	The maintenance processes are efficient and the equipment is reliable.

Source: adapted from Vera et al. (2021).

Based on the above, the following hypotheses were raised: Industrial Maintenance Management increases availability (general hypothesis), increases reliability and reduces the maintainability of equipment (specific hypotheses) in an electric utility company, Callao 2025.

2. Materials and Methods

The research was applied, as it sought to solve the low availability of the Bauker 6 kVA generator set through the application of Industrial Maintenance Management based on corrective and preventive maintenance. The approach was quantitative, since the indicators of both variables were expressed in numerical and percentage values, with two measurements (before and after) contrasted through significance tests. The level was explanatory, as it identified the causes of the problem to provide a solution, and the design was experimental of a pre-experimental type, with a single group evaluated in pre-test and post-test and a longitudinal scope (Ruiz & Valenzuela, 2022). The design scheme was GE → M_1 → E → M_2, where GE is the Bauker 6 kVA generator set, M_1 the availability pre-test, E the application of Industrial Maintenance Management and M_2 the post-test.

2.1. Population, sample and sampling

The unit of analysis was one week of recording maintenance orders for the 220 V generator set. The population consisted of 16 weeks of records of maintenance orders for the equipment used in the installation of electrical panels. The sample was equal to the population (16 weeks), distributed between the pre-test (July–October 2025) and the post-test (January–April 2026), so no sampling was applied. As inclusion criteria, only the records of failures and maintenance of the generator set were considered; tool calibrations were excluded, since they are performed once a year and do not depend directly on the company.

2.2. Technique and instrument

The technique used was documentary analysis and the instrument was the record sheet, applied to each dimension of the variables. The validity of the content was determined by the judgment of three experts with a master's degree from the César Vallejo University, who evaluated coherence, clarity and relevance and judged the instruments as approved. Reliability was verified using Cronbach's alpha coefficient in the SPSS v.25 software.

Table 2. Operationalization: variables, dimensions and indicators

Variable	Dimension	Indicator	Formula
Industrial Maintenance Management	Plan	% Planning Compliance	%CP=(DAILY/NTAPP)×100

	Do	% Execution Compliance	%EC = (NAE / NAP) × 100
	Verify	% Verification Compliance	%CV = (NOMA / TOE) × 100
	Act / Control	% Control Compliance	%CC = (NACI / NACID) × 100
Availability	Reliability	Reliability (%)	C = e^(−t/TMEF) × 100
	Maintainability	Maintainability (%)	M = (1 − e^(−t/TMR)) × 100

Source: Authors. Availability is calculated as D = FMSR / (FMSR + RMT).

2.3. Implementation procedure (PHVA cycle)

Plan. The criticality analysis of the generator set was carried out to prioritize the most relevant equipment and failures, and an initial diagnosis (DAP) of the maintenance process was carried out, whose time was 39 minutes per equipment.

Do. Eight staff training sessions were carried out (January–February 2026) on corrective and preventive maintenance, technical sheets, types of failures and concepts of availability, reliability and maintainability. The 2026 annual maintenance plan (annual kardex with monthly, quarterly, semi-annual and annual activities), the equipment technical sheet, the tool selection and use manual, the spare parts kardex, the maintenance procedures manual and the maintenance compliance form were prepared.

Verify. Compliance with the programmed activities was measured and the indicators of availability, reliability and maintainability were monitored through the registration sheets.

Act. The deviations detected were corrected and the procedures were standardized to sustain the improvement, based on the availability of spare parts in stock and appropriate tools.

2.4. Data analysis method and ethical aspects

The descriptive (mean, median, mode, standard deviation, variance, asymmetry and kurtosis) and inferential analysis were processed in SPSS v.25. Since the sample was less than 50, normality was evaluated with the Shapiro-Wilk test; since the assumption of normality was not met, the hypothesis testing was carried out with the non-parametric test of Wilcoxon signed ranges for related samples (Mayorga et al., 2021). Regarding ethical aspects, the company was authorized for the academic use of the information, the Code of Ethics of the César Vallejo University (Resolution No. 0659-2024) was respected, and the veracity and non-alteration of the data was guaranteed.

3. Results

3.1. Descriptive analysis

The application of Industrial Maintenance Management allowed to increase the average availability from 66.70 % (pretest) to 90.33 % (posttest), which is equivalent to an improvement of 35.42 %. This behavior is explained by the improvement of the scheduled maintenance plan, the early identification of faults and the reduction of intervention time from 39 to 36.3 minutes per piece of equipment. Reliability went from 78.88 % to 95.99 % (21.70 % increase), associated with the increase in FMGR from 4 to 12.23, while maintainability was reduced from 62.03 % to 53.34 % (14.01 % decrease), as a result of the reduction in the average repair time.

Table 3. Descriptive statistics of the variables (pre-test and post-test)

Statistician	Avail. Pre	Disp. Post	Conf. Pre	Conf. Post	Mant. Pre	Mant. Post
Media	66.70	90.33	78.88	95.99	62.03	53.34

Medium	66.67	92.31	77.88	95.96	60.65	47.24
Fashion	66.67	92.31	77.88	95.92	60.65	47.24
Desv. Standard	3.43	3.60	1.78	0.08	3.76	12.92
Variance	11.74	12.97	3.18	0.01	14.12	166.89
Asymmetry	−1.20	−0.44	1.28	0.14	2.51	0.24
Curtosis	3.65	−1.83	−0.44	−2.19	4.90	−1.67

Source: SPSS v.25.

In terms of availability, the mean rose substantially, maintaining a practically stable variability (variance from 11.74 to 12.97). In terms of reliability, the drastic reduction in the standard deviation (from 1.78 to 0.08) stands out, which shows highly uniform post-test results. In terms of maintainability, despite the decrease in the average value —desirable, since it implies more efficient repairs—, an increase in the standard deviation (from 3.76 to 12.92) is observed, attributable to the greater amplitude of intervention times after the improvement.

3.2. Inferential analysis

The Shapiro-Wilk test applied to the 16 records yielded significance values below 0.05 in all variables (pre-test and post-test), so normality was rejected and the non-parametric Wilcoxon test was chosen.

Table 4. Shapiro-Wilk normality test (df = 16)

Variable	Stage	Statistician	Say.
Availability	Pretest	0.546	0.000
Availability	Posttest	0.761	0.001
Reliability	Pretest	0.546	0.000
Reliability	Posttest	0.681	0.000
Maintainability	Pretest	0.398	0.000
Maintainability	Posttest	0.778	0.001

Source: SPSS v.25.

Contrast using the Wilcoxon sign rank test confirmed a statistically significant impact of the intervention on the three variables. In all cases, the bilateral asymptotic significance was less than 0.05, so the null hypothesis is rejected and the researcher's hypothesis is accepted: Industrial Maintenance Management increases availability and reliability, and reduces the maintainability of equipment.

Table 5. Wilcoxon sign rank test (posttest – pretest)

Variable	Z	Asymptotic sig. (bilateral)	Decision
Availability	−3,520	0.000	Ha accepted
Reliability	−3,550	0.000	Ha accepted
Maintainability	−2,515	0.012	Ha accepted

Source: SPSS v.25.

4. Discussion

The general objective was to determine how Industrial Maintenance Management increases equipment availability. The results showed an increase of 35.42% (from 66.70% to 90.33%), with a significance of 0.000 in the Wilcoxon test, confirming an effect not attributable to chance. This finding is consistent with the theoretical support that availability depends on the reliability and maintainability of equipment (Vera et al., 2021) and with recent evidence that availability is directly proportional to MTBF and inversely proportional to MTTR (Cirineo Loyola et al., 2025; Castello et al., 2025). The result is similar to that of Montalvo and Gonzáles (2024), who raised availability from 65.7% to 87.3% (32.88% improvement) supported by technological monitoring of critical equipment. Compared to Solórzano and Espinosa (2022) and Pillado and Castillo (2022), whose increases exceeded 116%, the difference is explained by the fact that these studies integrated the ISO 9001:2015 standard and more extensive annual maintenance plans, while the present work focused on the four stages of the PHVA and on the criticality analysis of three pieces of equipment.

Regarding the first specific objective, reliability increased by 21.70 % (from 78.88 % to 95.99 %; Wilcoxon = 0.000). This is associated with the increase in FMCT from 4 to 12.23, supported by the availability of spare parts in stock and adequate tools. The result converges with Solórzano and Espinosa (2022), who increased the time between failures through criticality analysis and FMEA, and with Becerra and Daviran (2021), who improved reliability from 69.8 % to 87.6 % through procedure manuals and annual programming. These findings are consistent with the literature that reports reliability improvements when implementing structured preventive maintenance programs (Ben et al., 2021).

Regarding the second specific objective, maintainability was reduced by 14.01 % (from 62.03 % to 53.34 %; Wilcoxon = 0.012), reflecting more efficient repairs thanks to scheduled maintenance and the prevention of sudden failures. The result is consistent with Ronceros (2022), who optimized intervention times through FMEA and PHVA, and with Nicho (2025) and Miran and Pari (2023), who reduced MTTR and downtime through periodic inspections and preventive maintenance plans. The reduction in maintainability, understood as less relative repair time, directly contributes to sustaining the increase in overall availability.

Overall, the results confirm that Industrial Maintenance Management, articulated under the PHVA cycle and supported by preventive and corrective maintenance, constitutes an effective strategy to increase the availability of critical equipment. Among the limitations of the study are the pre-experimental design with a single group and the small sample size (16 weeks, three teams), which restricts the generalization of the findings and suggests the convenience of quasi-experimental designs with a control group in future research.

5. Conclusions

It is concluded that Industrial Maintenance Management increases the availability of equipment in the electric service company: availability went from 66.70 % to 90.33 %, with an increase of 35.42 % and a significance of 0.000 in the Wilcoxon test, accepting the general hypothesis.

It is concluded that Industrial Maintenance Management increases the reliability of the equipment, which rose from 78.88 % to 95.99 % (increase of 21.70 %; Wilcoxon = 0.000), associated with the increase in FMGR from 4 to 12.23.

It is concluded that Industrial Maintenance Management reduces the maintainability of the equipment, which decreased from 62.03 % to 53.34 % (reduction of 14.01 %; Wilcoxon = 0.012), as a result of the reduction in the average repair time.

It is recommended that the company maintain the annual maintenance plan with a preventive, programmed corrective and predictive approach; carry out a monthly monitoring of availability, reliability and maintainability indicators; strengthen preventive activities in 220 V generator sets; and standardize diagnostic protocols, intervention sheets and availability of critical spare parts, as well as the continuous training of technical personnel.

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