

Total Productive Maintenance to Improve the Availability of Mechanical ICU Ventilators in a Public Hospital in la Victoria, 2025

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Received: 6th Dec, 2025; Revised: 4th Feb 2026; Accepted: 12th Feb, 2026; Available Online: 28th Feb, 2026

ABSTRACT

Objective: The objective of this study is to determine the impact of the implementation of Total Productive Maintenance (TPM) on the availability of mechanical ventilators in the Intensive Care Unit of a public hospital.

Methods: An applied research was carried out, employing a quantitative approach, using an explanatory level and a pre-experimental design. The population analyzed consisted of the weekly failure records of 20 mechanical ventilators. The aggregation of data was facilitated through the utilization of registration forms and checklists. Prior to the implementation of the intervention, indicators of availability, reliability, and maintainability were calculated. Subsequent to the intervention, a similar calculation was performed.

Results: The availability rate exhibited an increase from 69.26% to 82.61%, signifying an enhancement of 19.26%. Reliability demonstrated a notable increase, rising from 19.13% to 28.52%, representing a substantial 49.05% growth. The maintainability index exhibited a significant decline, from 2.74% to 0.59%, representing a substantial 78.31% reduction. The statistical analysis yielded a p-value of 0.00, thereby confirming the positive effect of the MPR.

Conclusion: The implementation of the TPM has been demonstrated to enhance the accessibility and functionality of mechanical ventilators within the intensive care unit (ICU), thereby serving as an effective strategy for optimizing the management of essential biomedical equipment.

Keywords: Total Productive Maintenance; availability; Reliability; Maintainability; Mechanical Ventilators.

How to cite this article: Gonzales Bramón NR, Dávila Laguna RF, Total Productive Maintenance to Improve the Availability of Mechanical ICU Ventilators in a Public Hospital in la Victoria, 2025. *Int J Drug Deliv Technol.* 2026;16(5s): 479-494. DOI: 10.25258/ijddt.16.5s.65

Source of support: Nil.

Conflict of interest: None

1. INTRODUCTION

Mechanical ventilation is a critical component of care for critically ill patients, as it ensures adequate oxygenation and the effective elimination of carbon dioxide in a regulated manner, thereby reducing the likelihood of respiratory complications and contributing to the patient's stability. In this context, the extant literature indicates that mechanical ventilation is vital in the treatment of patients who require constant life support in intensive care units. The availability of mechanical ventilation has been shown to significantly influence the effectiveness of treatments and the response capacity of the health team (Gutiérrez et al., 2020). This situation underscores the imperative to maintain the functionality of mechanical ventilators and to implement maintenance strategies that guarantee their uninterrupted operation.

In the Latin American context, the management of biomedical equipment maintenance is confronted with substantial challenges, primarily due to budgetary limitations, a shortage of specialized technical personnel, and the absence of institutional policies that prioritize preventive maintenance. In Colombia, research conducted in hospitals in Medellín has demonstrated that the absence of prevention measures and inadequate technical training have a direct impact on the malfunction of mechanical ventilators, resulting in critical delays in patient care (Agudelo, 2021). The findings indicate that the accessibility of biomedical equipment is contingent not solely on its acquisition, but also on the effective management of maintenance and the continuous monitoring of its performance.

This phenomenon is not exclusive to the United States; it also manifests in other nations within the region. In the context of the ongoing health crisis in Venezuela,

precipitated by the global pandemic of the novel Coronavirus (SARS-CoV-2), it has been documented that the government's capacity to meet the demand for mechanical ventilators was found to be severely inadequate, with reports indicating that it was only able to fulfill a mere 9% of the requisite needs (Human and Rights, 2019). This critical situation has led to a pronounced crisis in the care of patients requiring critical care, underscoring the critical condition of the healthcare system with regard to the availability and maintenance of such critical equipment. This situation demonstrated the repercussions of an absence of an effective strategy for the maintenance and replacement of equipment, which hindered the ability to respond to high-demand emergencies.

In the case of Peru, several reports indicate that a considerable number of mechanical ventilators are not operational due to unresolved technical failures, lack of preventive maintenance protocols, and operational deficiencies, such as the lack of compressed medical air. In the Metropolitan Lima region, the Comptroller General of the Republic (2023) reported that 17 mechanical ventilators at the Archbishop Loayza National Hospital were inoperable due to a lack of essential maintenance. These cases underscore a national predicament concerning the dearth of comprehensive maintenance policies and the paucity of skilled technical personnel.

At the medical center where this study was conducted, mechanical ventilators have been observed to experience unexpected failures, which in turn have led to disruptions in the care of both critical and non-critical patients. This phenomenon underscores the pressing need to enhance the effectiveness of maintenance processes. The institution, which seeks to guarantee access to health services universally, equitably, and free of charge, faces the challenge of ensuring that these essential devices function continuously. The identification of recurrent failure events within the intensive care unit underscores the necessity for maintenance strategies that aim to minimize operational downtime and enhance ventilator efficiency.

Availability, defined as the degree to which a device is prepared for immediate use, serves as a critical metric for assessing performance. Gutiérrez et al. (2020) posit that a high level of availability signifies that equipment is operational the majority of the time. Conversely, Rayme and Díaz (2021) describe it as the probability that a device will fulfill its function when it is required. In a similar vein, the reliability and maintainability of fans must be assessed to evaluate their condition and performance. The Mean Time Between Failures (MTBF) is defined as the average operating time of the equipment between one breakdown and another (Rayme & Díaz, 2021), while the Mean Time to Repair (MTTR) is the interval necessary for the equipment to be operational again after a failure.

Consequently, the extant literature underscores the significance of other pertinent terms within the domain of maintenance. Downtime is defined as the period during which equipment is inoperable due to failures or repairs (Zegarra & Mendoza, 2024). Preventive maintenance is defined as the implementation of scheduled actions aimed at averting malfunctions before they materialize (Rayme & Díaz, 2021). Conversely, corrective maintenance is initiated subsequent to the occurrence of a failure (Villón, 2020). In contrast, unscheduled stops represent unanticipated disruptions, which have been shown to compromise service continuity (Marrero et al., 2022). These terms facilitate the identification of factors contributing to low availability and provide a framework for developing strategies to enhance it.

In the context of this situation, Total Productive Maintenance (TPM) emerges as a methodology that prioritizes the mitigation of failures, the reduction of downtimes, and the standardization of processes, encompassing the involvement of maintenance personnel and operators. Porras (2025) posits that the implementation of TPM leads to the elimination of unanticipated failures, enhances the quality of maintenance, and optimizes the operation of the equipment. This participatory approach to the TPM aims not only to rectify existing failures but also to proactively prevent them through systematic actions that enhance the reliability of the system.

A substantial body of research has demonstrated the efficacy of the TPM in enhancing availability rates. Campoverde, Loor, and Guevara (2024) reported significant increases of more than 25% in the availability of critical machinery in the rice industry after the implementation of this methodology. These findings suggest that the TPM can be effectively adapted to the hospital environment, where the continuous operation of biomedical equipment is paramount.

This research employed a range of analytical tools, including the Ishikawa diagram, the Vester matrix, and the Pareto diagram, to identify the primary factors influencing the availability of mechanical ventilators. These include the absence of availability indicators, inadequate technical training, staff exhaustion, limited control over maintenance scheduling, failure to measure, and non-compliance with prevention routines. These factors constitute 20% of the elements that produce 80% of the problems, underscoring the pressing need to adopt a comprehensive maintenance approach.

The objective of the present research is to provide an answer to the following question: The present study seeks to investigate the influence that the implementation of Total Productive Maintenance will have on the availability of ICU mechanical ventilators in a public hospital. To further explore the potential

impact of TPM on the reliability and maintenance requirements of these devices, which are essential for ensuring operational efficiency, more specific inquiries were posed.

The underlying rationale for this study is to employ an approach that can effectively address real-world problems through the utilization of practical tools. Arias (2021) posits that the practice is intended to address specific problems and proffers solutions that can be employed to enhance particular domains or circumstances. This assertion lends support to the pertinence of TPM as a methodology for optimizing the availability of mechanical ventilators. Moreover, from a methodological perspective, this research is predicated on the necessity of creating indicators that facilitate statistical analysis of maintenance performance and guide decision-making.

2. OBJECTIVES

2.1 General objective

The objective of this study is to ascertain the extent to which the Total Productive Maintenance Application enhances the availability of mechanical ventilators in intensive care units within public hospitals.

2.2 Specific objectives

- To determine how the Total Productive Maintenance Application improves the reliability of ICU mechanical ventilators in Public Hospitals
- To determine how the Total Productive Maintenance Application reduces the maintainability of ICU mechanical ventilators in Public Hospitals

3. THEORETICAL FRAMEWORK

Mechanical ventilation is presented as an essential support for critically ill patients in Intensive Care Units (ICUs), as it facilitates the replacement or assistance of respiratory function in cases of severe insufficiency. As stated in the relevant literature, its use is imperative to maintain hemodynamic stability and ensure adequate gas exchange in patients who are unable to breathe independently (Gutiérrez et al., 2020). In light of the gravity of this service, the uninterrupted operation of mechanical ventilators becomes imperative within health institutions, as the failure or unavailability of these devices poses a significant risk to patient lives. In this context, it is acknowledged that maintenance management constitutes a foundational element within the domain of hospital administration. The implementation of strategies that ensure optimal operational functionality is, therefore, imperative.

From an engineering maintenance perspective, biomedical equipment, particularly mechanical ventilators, necessitate constant supervision in accordance with technical indicators that facilitate the evaluation of their operational performance over time. The indicators under consideration include Mean Time Between Failures (MTBF), Operational Availability,

and Mean Time to Repair (MTTR). The mean time between failures (MTBF) is a metric that indicates the average number of hours of effective use before failure occurs. This metric allows for the evaluation of the reliability of the device (Rayme & Díaz, 2021). An increase in the mean time between failures (MTBF) indicates that equipment can operate for extended periods without interruption, a crucial consideration in emergency situations. Conversely, MTTR quantifies the average time required for equipment to be restored to operational status following a malfunction, exhibiting a direct correlation with maintainability. A reduced mean time to repair (MTTR) indicates enhanced efficiency in the maintenance process and reduced disruptions to clinical services.

Operational readiness is a multifaceted concept that integrates these two indicators, measuring the ratio between effective operating time and total service time. As demonstrated by Gutiérrez et al. (2020), this indicator is a comprehensive measure that reflects the true capacity of the equipment to be in use when needed. In critical care settings, such as intensive care units (ICUs), the concept of availability extends beyond mere technical considerations, becoming a metric of patient safety and the quality of care provided. The observed decrease in availability can be attributed to various factors, including unexpected breakdowns, protracted repair times, inadequate preventive maintenance, and insufficient technical infrastructure. These factors can impede the effectiveness of health personnel in critical situations.

Rayme and Díaz (2021) posit that preventive maintenance encompasses a series of deliberate actions intended to avert the onset of failures through systematic inspections, calibrations, and the scheduled replacement of components. This maintenance strategy is designed to ensure the continuous operation of the system and to mitigate the risk of unanticipated events. Conversely, corrective maintenance is implemented subsequent to the occurrence of failure (Villón, 2020), which can result in periods of downtime that adversely affect patient care. Additionally, unanticipated interruptions in equipment operation, classified as unplanned stoppages, are a primary contributor to low availability, constituting a substantial risk to clinical operability (Marrero et al., 2022). Proper management of these types of maintenance is crucial to ensure the optimal operation of mechanical ventilators.

In this framework, Total Productive Maintenance (TPM) is presented as a comprehensive approach that tries to maximize the efficiency and availability of equipment through the coordinated collaboration of technical, operational, and administrative personnel. Porras (2025) posits that the implementation of TPM leads to a substantial reduction in the incidence of unanticipated failures, enhances the quality of maintenance, and contributes to an enhancement in reliability. The TPM encompasses pillars such as

autonomous maintenance, scheduled maintenance, continuous improvement, technical training, safety management, and process standardization. These pillars facilitate the establishment of a robust and sustainable maintenance system.

The efficacy of the TPM has been demonstrated in a variety of productive sectors. Campoverde, Loo, and Guevara's (2024) findings indicated that the implementation of the initiative within the rice industry resulted in a substantial increase of over 25% in the availability of essential machinery. While these experiences originate from industrial contexts, the principles can be effectively applied to biomedical equipment, whose continuous operability is paramount. The implementation of these methodologies within a hospital setting serves to fortify maintenance management by establishing systematic routines and fostering ongoing enhancement of processes.

Beyond the utilization of technical metrics, the domain of maintenance engineering involves the employment of analytical tools to ascertain underlying causes and to establish a prioritized sequence of actions. The Ishikawa diagram is a tool that facilitates the visualization of potential causes of a problem, systematically organizing them into categories such as materials, methods, machinery, labor, measurement, and environment. The Vester matrix is a supplementary tool that evaluates the interrelationships among causes, assigning scores that facilitate the identification of salient factors. The Pareto diagram is employed to categorize these causes according to their effect, thereby demonstrating that a limited number of factors are responsible for the majority of problems. The use of this toolkit in unison fosters a comprehensive comprehension of the challenges impeding the accessibility of biomedical equipment.

Research in hospital administration has identified several factors that contribute to the continuous operation of mechanical ventilators. These factors include a lack of metrics, inadequate training programs, insufficient maintenance controls, poor standardization of procedures, and the absence of systematic follow-up. As Marrero et al. (2022) have demonstrated, unanticipated interruptions and delays in repairs have a direct impact on patient safety and impose an additional strain on health systems. Concurrently, Zegarra and Mendoza (2024) have indicated that protracted inactivity of vital biomedical devices can result not only in financial losses, but also in failures in the chain of care.

In this context, the importance of enhancing the management of biomedical maintenance is evident, particularly in public hospitals where demand is high and resources are limited. The implementation of methodologies such as TPM has been demonstrated to be a viable and effective strategy for improving operational performance indicators. These

methodologies facilitate the systematic visualization of failures, the organization of interventions, the training of technical personnel, and the assurance of process sustainability through continuous monitoring of performance indicators.

In summary, the set of concepts, approaches, and indicators reviewed herein allows for the theoretical and methodological support of the application of the MPT as a comprehensive intervention strategy aimed at improving the availability of mechanical ventilators in ICUs. The extant literature supports the validity of this approach, demonstrating its capacity to reduce failures, shorten repair times, and enhance the operational efficiency of critical biomedical equipment.

4. METHODOLOGY

The research was conducted with an applied approach, as its objective was to address a particular problem in the hospital setting: the shortage of mechanical ventilators in the Intensive Care Unit. The objective of this investigative approach is to identify pragmatic solutions by employing novel techniques and procedures that address the underlying causes of the problem, as delineated in the original research methodology.

The approach employed was quantitative, as numerical data were utilized to assess the dimensions of the variables under consideration, including the availability, reliability (MTBF), and maintainability (MTTR) of mechanical ventilators. The measurements were presented in the form of percentages to facilitate an unbiased statistical analysis of the results obtained.

The research method employed was of an explanatory nature, as it focused on examining how the implementation of Total Productive Maintenance (TPM) affected the performance indicators of biomedical equipment. The study design employed a pre-experimental approach, which entailed the observation of a single group before and after the intervention. The specific design that was implemented was as follows:

$$GE \rightarrow O1 \rightarrow X1 \rightarrow O2,$$

The experimental group (EG) comprised 20 mechanical ventilators from the intensive care unit (ICU). The initial observation was denoted by O1, the implementation of the TPM by X1, and the post-intervention observation by O2.

The study population comprised all weekly failure records of the 20 mechanical ventilators in the intensive care unit of the public hospital, and the sample size was equivalent to the total number of records, thus constituting a non-probabilistic convenience sampling method. The analysis unit comprised a comprehensive set of weekly records documenting mechanical ventilator failures.

The data collection process involved the utilization of registration forms, checklists, document analysis, and field observation, in accordance with the protocols established by the maintenance area. These techniques facilitated the acquisition of information regarding failures, operating times, repair times, and the execution of preventive and corrective maintenance.

The indicators employed in this study were those characteristic of maintenance engineering, including:

- MTBF (Mean Time Between Failures), defined as the average correct operating time between one fault and the next.
- MTTR (Mean Time to Repair), understood as the average time required to repair equipment and return it to normal operation.
- Operational Availability, measured as the time in which the equipment is operational with respect to the total time considered, as proposed by Rayme and Diaz (2021).

The calculation of availability was carried out under the standard formula:

$$D = \frac{MTBF}{MTBF + MTTR}$$

In addition to the quantitative analysis, quality tools were employed to identify and prioritize the underlying causes of the problem. An Ishikawa diagram was developed, in which 20 causes were identified and grouped into the categories of the 6M. Subsequently, the Vester matrix was applied, yielding a total score of 439 for the active causes, which enabled the assessment

of their influence. A Pareto diagram was subsequently developed, delineating six primary causes that accounted for 80% of the impact on the low availability of mechanical ventilators. These causes encompassed a lack of availability indicators, inadequate training, staff fatigue, noncompliance with maintenance schedules, inadequate control in scheduling, and the absence of failure and repair indicators.

The selection of TPM as an intervention methodology was substantiated by the capacity of this approach to address priority causes through structured procedures that encompass autonomous maintenance, planned maintenance, technical training, standardization of routines, monitoring of indicators, and focused improvement.

A comparative analysis and statistical tests were subsequently conducted on the data collected prior to and following the intervention to ascertain the significance of the enhancements in availability, reliability, and maintainability that were achieved subsequent to the implementation of the TPM.

5. RESULTS

This study has considered evaluating through two types of analysis, descriptive and inferential. Firstly, with regard to descriptive analysis, this term refers to the component of statistics that organizes information in such a manner that it can be examined and interpreted. Descriptive approaches in statistics facilitate the realization of descriptive statistical methods, such as the central tendency, variability, and distribution of the variable (Sucasaire, 2021).

The ensuing descriptive analysis of availability will present the results obtained from the two aforementioned stages.

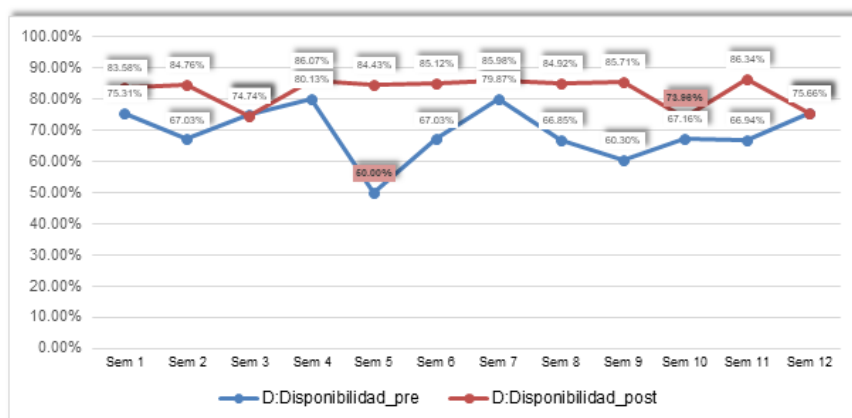


Figure 1. Results of availability during the 12 weeks

Source: Own elaboration

As illustrated in Figure 1, the post-test values exceed the pre-test values, indicating that during the initial stage (pre), there was a decrease in availability in Week 5. In contrast to the enhanced stage, which exhibited a decline in week 10, a detailed analysis was conducted to ascertain the underlying causes. It was determined that

the personnel were not adhering to the established protocols, failing to provide the requisite feedback, and demonstrating an insufficient level of oversight. Subsequently, the information from the 12-week period was entered into the SPSS, encompassing both the pre- and post-stages. This resulted in the generation of a

descriptive table that elucidated the availability. The following details were incorporated into Table 1.

Table 1. Availability Description

		D PRE	D POST
N	Valid	12	12
	Lost	0	0
Stocking		69,2625	82,6058
Median		67,0950	84,8400
Fashion		67,03	73.96a
Desv. Standard		8,61422	4,79038

Source: SPSS version 25

This table illustrates that the level of availability exhibited a substantial enhancement following the intervention. The mean score increased from 69.26 in the pre-test period to 82.61 in the post-test period, indicating a significant enhancement in the performance of the indicator. Concurrently, the median value exhibited an upward shift from 67.10 to 84.84, thereby

substantiating the central tendency's deviation towards elevated values. This development signifies a pervasive enhancement within the sample population under scrutiny. In a similar manner, the results of the Descriptive Reliability Analysis (first dimension) that have been entered into SPSS from the two stages are initially displayed.

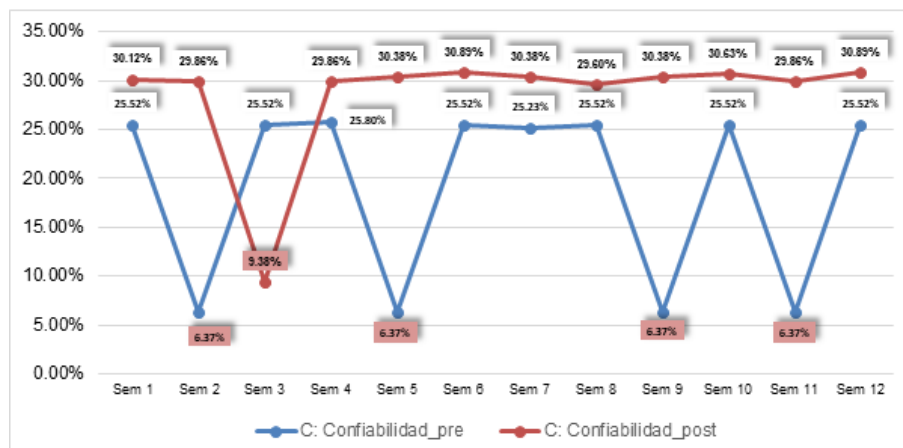


Figure 2. Reliability results over the 12 weeks.

Source: Own elaboration

Figure 2 shows that the post-test values are higher than the pre-test, evidencing that for the initial stage (pre) there was a decrease in reliability in weeks 2, 5, 9 and 11 since the time between failures was 102. Unlike the improved stage that registered the change during the 3 weeks because the time between failures was 135.

Which, the reason was analyzed, identifying that the staff is complying with the established changes. Then, the information for the 12 weeks, shown from both stages (pre and post) was entered into the SPSS, showing the descriptive table of reliability (Table 2).

Table 2. Reliability Description

		C PRE	C POST
N	Valid	12	12
	Lost	0	0
Stocking		19,1358	28,5192
Median		25,5200	30,2500
Fashion		25,52	29.86a
Desv. Standard		9,42898	6,04165

Source: SPSS version 25

In the table, it can be seen that the level of reliability shows a significant improvement after the intervention. The average went from 19.13 in the pre-test period to 28.52 in the post-test, evidencing a notable increase in the performance of the indicator. Likewise, the median

increased from 25.52 to 30.25, which confirms that the central trend shifted towards higher values, showing a generalized improvement in the sample. In addition, for the Descriptive Analysis of Maintainability, the results entered into the SPSS of the two stages are first shown:

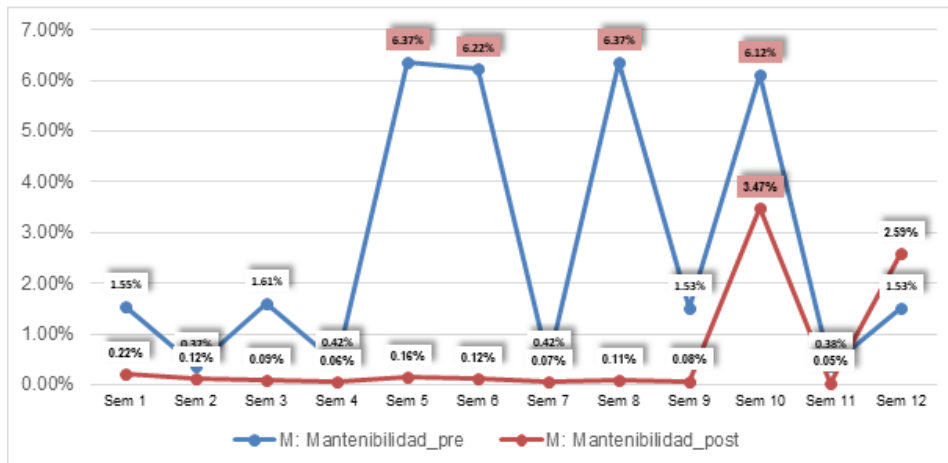


Figure 3: Results of maintainability over the 12 weeks.

Source: Own elaboration

Figure 3 shows that the post-test values are higher than the pre-test, showing that for the initial stage (pre) there was a decrease in maintainability in weeks 5, 6, 8 and 10, due to the fact that the repair time was 44. Unlike

the improved stage, which registered the change during the 12 weeks due to the better repair time was 28. Which, the reason was analyzed, identifying that the staff is complying with the established changes.

Table 3. Descriptive of maintainability

		M PRE	M POST
N	Valid	12	12
	Lost	0	0
Stocking		2,7408	,5950
Median		1,5400	,1150
Fashion		.42a	,12
Desv. Standard		2,65366	1,15369

Source: SPSS version 25

In Table 3, it can be seen that the level of maintainability shows a significant reduction after the intervention. The average went from 2.74 in the pre-test period to 0.60 in the post-test, evidencing a notable reduction in the performance of the indicator. Likewise, the median increased from 1.54 to 0.12, which confirms that the central trend shifted towards higher values, showing a generalized improvement in the sample.

or infer characteristics or expected outcomes of a population, based on data collected from a sample of that population (Sucasaire, 2021).

For the inferential test, in the SPSS of the two stages of availability, normality and hypothesis were analyzed, indicating the following:

In relation to inferential analysis, inferential analysis refers to a section of statistics that attempts to anticipate

For normal availability, the following decision rule was applied for selection based on sample size (Table 4).

Table 4. Decision rule for choosing evidence

DECISION RULE FOR CHOOSING EVIDENCE	
For small samples (n ≤ 50)	The Shapiro-Wilk test should be used. It is considered more powerful and reliable for this sample size range.
For large samples (n > 50)	The Kolmogorov-Smirnov test should be used. It is the recommended test for large datasets.

So, according to the table above, this study considered the Wilcoxon test because the sample was 12 weeks old,

it is small less than 50. The following is shown in Table 5.

Table 5. Availability normality testing

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistical	G1	Gis.	Statistical	G1	Gis.
D PRE	,223	12	,102	,899	12	,153
D POST	,331	12	,001	,708	12	,001

Source: SPSS version 25

Then the following decision rule applies in Table 6.

Table 6. Normality decision rule.

NORMALITY DECISION RULE	
H0: Data come from a population with normal distribution	H1: Data do not come from a population with normal distribution
If the significance value (Sig.) > 0.05	The null hypothesis is not rejected. This means that there is not enough evidence to conclude that the data is not normal. The variable is assumed to have a normal distribution
If the significance value (Sig.) ≤ 0.05	The null hypothesis is rejected. This indicates that the data deviates significantly from a normal distribution. In this case, the variable does not meet the assumption of normality.

So, according Table 6, the values of the normality of availability were different, one greater than 5% and the other less than 5%, so it was non-parametric, to proceed to apply the hypothesis test according to Wilcoxon:

For the availability hypothesis, the following decision rule was applied for selection based on sample size, as shown in Table 7.

Table 7. Decision rule for the hypothesis.

DECISION RULE FOR THE HYPOTHESIS	
Null hypothesis (H 0): There is no difference between the medians of the two samples	Alternative hypothesis (H1): There is a significant difference between the medians of the two samples.
If the p-value is less than or equal to 0.05 ($p \leq 0.05$)	The null hypothesis (H0) is rejected. This means that the observed difference is statistically significant and not due to chance. Therefore, it is concluded that there is a difference between the medians of the two samples.
p-value is greater than 0.05 ($p > 0.05$)	The null hypothesis (H0) is not rejected. This means that there is not enough evidence to conclude that there is a significant difference between the medians. The difference observed could be the product of chance.

The following hypotheses were raised:

Ha: The Total Productive Maintenance SI Application reduces the availability of ICU mechanical ventilators in Public Hospital

Ho: The Total Productive Maintenance Application does NOT reduce the availability of ICU mechanical ventilators in Public Hospital

Table 8. Availability Wilcoxon.

	D PRE - D POST
Z	-2.903b
Asymptotic sig. (bilateral)	,004

Source: SPSS version 25

Therefore, the value of the sig (pvalue) was 0.004 less than 5% (0.05) affirming the Ha (The Total Productive Maintenance SI Application improves the availability of ICU mechanical ventilators in Public Hospital), canceling the Ho.

For the inferential test, in the SPSS of the two stages of reliability, normality and hypothesis were analyzed, indicating the following:

For reliability normality, the following decision rule was applied for selection based on sample size:

Table 9. Decision rule for choosing evidence

DECISION RULE FOR CHOOSING EVIDENCE	
For small samples ($n \leq 50$)	The Shapiro-Wilk test should be used. It is considered more powerful and more reliable for this sample size range.
For large samples ($n > 50$)	The Kolmogorov-Smirnov test should be used. It is the recommended test for large datasets.

So, according to Table 9, this study considered the is small less than 50. The following is shown in Table Wilcoxon test because the sample was 12 weeks old, it 10.

Table 10. Reliability normality testing

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistical	G1	Gis.	Statistical	G1	Gis.
C PRE	,408	12	,000	,617	12	,000
C POST	,488	12	,000	,391	12	,000

Source: SPSS version 25

Then the following decision rule applies (Table 11).

Table 11. Normality decision rule

NORMALITY DECISION RULE	
H0: Data come from a population with normal distribution	H1: Data do not come from a population with normal distribution
If the significance value (Sig.) > 0.05	The null hypothesis is not rejected. This means that there is not enough evidence to conclude that the data is not normal. The variable is assumed to have a normal distribution
If the significance value (Sig.) ≤ 0.05	The null hypothesis is rejected. This indicates that the data deviates significantly from a normal distribution. In this case, the variable does not meet the assumption of normality.

Then, according to the table of the value of the normality of the reliability were lower, then it is concluded that the data do not follow a normal distribution which requires a non-parametric test such as the Wilcoxon test.

For the reliability hypothesis, the following decision rule was applied for selection based on sample size:

Table 12. Decision rule for the hypothesis

DECISION RULE FOR THE HYPOTHESIS	
Null hypothesis (H 0): There is no difference between the medians of the two samples	Alternative hypothesis (H1): There is a significant difference between the medians of the two samples.
If the p-value is less than or equal to 0.05 ($p \leq 0.05$)	The null hypothesis (H0) is rejected. This means that the observed difference is statistically significant and not due to chance. Therefore, it is concluded that there is a difference between the medians of the two samples.
p-value is greater than 0.05 ($p > 0.05$)	The null hypothesis (H0) is not rejected. This means that there is not enough evidence to conclude that there is a significant difference between the medians. The difference observed could be the product of chance.

The following hypotheses were raised:

Ha: The Total Productive Maintenance SI Application reduces the reliability of ICU mechanical ventilators in Public Hospital

Ho: The Total Productive Maintenance Application does NOT reduce the reliability of ICU mechanical ventilators in Public Hospital

Table 13. Reliability Wilcoxon

	C PRE - C POST
Z	-2.435b
Asymptotic sig. (bilateral)	,015

Source: SPSS version 25

Therefore, the value of the sig (pvalue) was 0.015 less than 5% (0.05) affirming the Ha (The Total Productive Maintenance SI Application improves reliability of ICU mechanical ventilators in Public Hospital), canceling the Ho.

For the inferential test, in the SPSS of the two stages of maintainability, normality and hypothesis were analyzed, indicating the following:

For normality of maintainability, the following decision rule was applied for selection based on sample size:

Table 14. Decision rule for choosing evidence

DECISION RULE FOR CHOOSING EVIDENCE	
For small samples ($n \leq 50$)	The Shapiro-Wilk test should be used. It is considered more powerful and more reliable for this sample size range.
For large samples ($n > 50$)	The Kolmogorov-Smirnov test should be used. It is the recommended test for large datasets.

So, according to Table 14, this study considered the is small less than 50. The following is shown in Table Wilcoxon test because the sample was 12 weeks old, it 15.

Table 15. Normality testing of maintainability

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistical	Gl	Gis.	Statistical	Gl	Gis.
M PRE	,332	12	,001	,736	12	,002
M POST	,461	12	,000	,522	12	,000

Source: SPSS version 25

Then the following decision rule applies (Table 16).

Table 16. Normality decision rule.

NORMALITY DECISION RULE	
H0: Data come from a population with normal distribution	H1: Data do not come from a population with normal distribution
If the significance value (Sig.) > 0.05	The null hypothesis is not rejected. This means that there is not enough evidence to conclude that the data is not normal. The variable is assumed to have a normal distribution
If the significance value (Sig.) ≤ 0.05	The null hypothesis is rejected. This indicates that the data deviates significantly from a normal distribution. In this case, the variable does not meet the assumption of normality.

So, according to the table of the value of the normality of maintainability, the values yielded were both lower than the level of significance which is 0.05. Then the null hypothesis (H0) is rejected, therefore, the data do not follow a normal distribution, which requires the use of a non-parametric test such as the Wilcoxon test.

For the maintainability hypothesis, the following decision rule was applied for selection based on sample size (Table 17).

Table 17. Decision rule for the hypothesis.

DECISION RULE FOR THE HYPOTHESIS	
Null hypothesis (H 0): There is no difference between the medians of the two samples	Alternative hypothesis (H1): There is a significant difference between the medians of the two samples.
If the p-value is less than or equal to 0.05 ($p \leq 0.05$)	The null hypothesis (H0) is rejected. This means that the observed difference is statistically significant and not due to chance. Therefore, it is concluded that there is a difference between the medians of the two samples.
p-value is greater than 0.05 ($p > 0.05$)	The null hypothesis (H0) is not rejected. This means that there is not enough evidence to conclude that there is a significant difference between the medians. The difference observed could be the product of chance.

The following hypotheses were raised:

Ha: The Total Productive Maintenance SI Application reduces the maintainability of ICU mechanical ventilators in Public Hospital

Ho: The Total Productive Maintenance Application does NOT reduce the maintainability of ICU mechanical ventilators in Public Hospital

Table 18. Wilcoxon of maintainability

	M PRE - M POST
Z	-2,667b
Asymptotic sig. (bilateral)	,008

Source: SPSS version 25

Therefore, the value of the sig (pvalue) was 0.008 less than 5% (0.05) affirming the Ha (The Total Productive Maintenance Application DOES reduce the maintainability of ICU mechanical ventilators in Public Hospital), canceling the Ho.

6. DISCUSSION

The findings obtained in this research clearly demonstrate the favorable effect that the adoption of Total Productive Maintenance (TPM) had on the operational performance of mechanical ventilators in the Intensive Care Unit. The simultaneous improvement in availability, reliability and maintainability proves that orderly maintenance management is essential to ensure continuity of medical service and the safety of critically ill patients.

The significant increase in availability, which went from 69. 26% to 82. 61%, represents a notable advance within the hospital environment. The literature supports that availability is one of the most relevant criteria for measuring the response capacity of the health system (Gutiérrez et al., 2020). The intervention helped to reduce the number of unscheduled shutdowns, improve preventive maintenance tasks and normalize processes that were previously executed reactively. This supports what Rayme and Díaz (2021) state, who indicate that availability is directly related to the balance between failures and repair times, aspects that are optimized by applying systematic maintenance practices.

Similarly, the improvement in reliability, with an increase in MTBF of 19. 13% to 28. 52%, validate that the intervention reduced the failure rate. Reliability is seen as a key indicator in critical equipment, as frequent failures disrupt not only medical care, but also put patient safety at risk. The decrease in failures is aligned with the diagnostic stage, where tools such as the Ishikawa diagram and the Vester matrix helped identify significant causes, such as lack of indicators, limited technical training, staff fatigue and lack of control in programming. This methodology of root cause analysis—common in industrial engineering but rare in hospitals—proved especially valuable in guiding effective interventions.

With regard to maintainability, the reduction of the MTTR of 2. 74 hours to 0. 59 hours is one of the most outstanding achievements of the study. A decrease of 78. 31% in repair times indicates a considerable improvement in the ability of technical staff to restore equipment to functional condition. According to

Marrero et al. (2022), long repair times are one of the main causes of downtime in hospital equipment. The standardization of procedures, the accessibility of inputs and tools, the improvement in internal organization and the clear assignment of responsibilities explain this transformation. The decrease in MTTR not only increased availability, but also promoted a more efficient and agile organizational culture.

The behavior of the indicators after implementing the TPM corresponds to what Porras (2025) indicates, who states that this methodology helps to eliminate unforeseen failures, improve the quality of technical interventions, and encourage staff participation. Likewise, the results coincide with the conclusions of the study carried out by Campoverde, Loor, and Guevara (2024), which indicates that the application of TPM in industrial equipment has significantly increased its availability. Although this research focuses on the industrial sector, its agreement with the results of this work shows that the principles of the TPM are applicable in any context and can be effectively adapted to the hospital environment, provided that there is institutional will and the processes are appropriately adjusted.

An important contribution of this research is that it documents, in the context of hospitals in Latin America, the way in which a methodology traditionally used in factories can be transformed to manage critical biomedical equipment. The literature indicates that the absence of standardized protocols, performance indicators, and technical training are common obstacles that impact biomedical maintenance in middle-income countries (Zegarra & Mendoza, 2024). The experience gained supports this statement and shows that the implementation of the TPM helps to close these structural gaps through concrete actions such as the development of indicators, the creation of maintenance routines and the training of personnel.

However, adopting the TPM was not a smooth process. As the theory states, this approach demands constant commitment, discipline in the performance of autonomous tasks and active participation of operational personnel. In the case of the hospital, work fatigue, high care loads and staff turnover complicated the adoption of systematic routines at the beginning. However, the results reveal that, once the procedures are established, the benefits outweigh the costs of their implementation. This tension between the demand for

care and scheduled maintenance is a crucial aspect in public hospitals and represents a constant challenge for the sustainability of the TPM.

Another significant contribution of the study is the statistical evidence collected. The p -value = 0.00 confirms that the changes observed were not accidental, but the direct result of the intervention. This provides robustness to the findings and supports the hypothesis that TPM is effective in improving the availability of biomedical equipment. From a methodological perspective, this finding gives internal validity to the study and reinforces the recommendation to establish the TPM as an institutional policy, especially in areas where continuity of service is essential.

In practical terms, improving the three indicators – availability, reliability and maintainability – has a positive impact not only on equipment management, but also on service quality. Greater availability guarantees timely care for critical patients; an increase in MTBF reduces the risk of unexpected failures; and lower MTTR ensures rapid interventions at times when time is a key resource. In addition, these results have economic repercussions, since they reduce the costs associated with failures, spare parts, urgent acquisitions and additional repair times.

Finally, it is essential to consider the long-term viability of the TPM. Studies indicate that progress is often lost if there is no regular and constant monitoring (Villón, 2020). Therefore, it is crucial to formally establish indicators, add routines to the annual maintenance program, strengthen technical training, and foster a culture of shared responsibility between operators and technicians. If this is not carried out, the hospital could fall back into a reactive approach that would put the availability of ventilators at risk.

7. CONCLUSIONS

The results of this study allow us to conclude that the introduction of Total Productive Maintenance (TPM) had a very positive impact on the operational indicators of the mechanical ventilators of the Intensive Care Unit of the hospital analyzed. The improvements achieved show that a maintenance system that was characterized by its reactivity, lack of standards and the absence of indicators can be transformed into a model that prioritizes prevention, is well organized and focuses on continuous improvement. This methodological transformation had direct effects on the technical performance of the teams and on the quality of the clinical service.

In relation to availability, the increase of 69.26% to 82.61% demonstrate that TPM helped significantly reduce unplanned downtime. The systematic implementation of preventive activities, the standardization of processes, and stricter maintenance scheduling facilitated the decrease in both the frequency and duration of periods in which equipment was not operational. This finding is particularly important in a critical care setting, where

the immediate availability of mechanical ventilators may influence the opportunity for care and patient survival.

Regarding reliability, the MTBF increased by 49.05% evidence that mechanical ventilators worked for longer periods without failure. This improvement is closely linked to identifying root causes, fixing repeated failures, and applying systematic monitoring routines. Reducing breakdowns not only increases the technical performance of equipment, but also reduces the workload for clinical and technical staff, avoiding interruptions at critical moments. This increase in reliability strengthens the operational resilience of the service and decreases the need for unplanned corrective interventions.

In terms of maintainability, the MTTR decreased by 78.31% are positioned as one of the most significant achievements of the study. The ability to quickly restore the functionality of mechanical ventilators translates into less waiting time for patients and less operational pressure on care units. The standardization of procedures, the improvement in the availability of tools and spare parts, as well as the training of personnel explain this notable decrease in repair times. This indicator, in addition to optimizing technical efficiency, directly contributes to increasing the overall availability of the system.

In a global framework, the concurrent improvement of these three indicators—availability, reliability, and maintainability—proves that TPM is a sound and effective method for managing the maintenance of critical biomedical equipment. The statistical significance achieved ($p = 0.00$) supports the main hypothesis of the study and gives scientific validity to the intervention carried out. The results confirm that, even in contexts where infrastructure, technical equipment and budget allocation are usually limited, continuous improvement methodologies can be implemented that generate significant impacts on the operability of hospital equipment.

Likewise, this research highlights that the diagnostic stage was key to the success of the intervention. The application of the Ishikawa diagram, the Vester matrix, and the Pareto diagram helped to clearly identify the main causes affecting the operation of mechanical ventilators. Among these causes were the lack of indicators, the lack of technical training, the overload of personnel and the non-compliance with maintenance programs. This detailed understanding of the problem allowed the TPM intervention to be directed towards the most critical aspects, which contributed to improving the efficiency of the process.

In addition, the findings highlight the importance of adopting comprehensive maintenance methods in the hospital sector. The TPM not only caused instant improvements in technical indicators, but also promoted the creation of an organizational culture focused on co-

responsibility, standardization, and commitment to quality. In an environment where patient care depends heavily on the reliability of biomedical equipment, reinforcing these practices is essential to ensure continuity of service and clinical safety.

Finally, it is concluded that the continuous implementation of the TPM is an effective and high-impact strategy for public hospitals facing significant operational challenges. The experience gained in this study shows that, with proper planning, monitoring, and institutional commitment, the performance of critical equipment can be considerably improved, optimizing available resources and raising the quality of care. However, maintaining these achievements requires maintaining operational discipline, continuously updating the technical skills of the staff and establishing a system of constant monitoring of indicators that ensures the continuous improvement of the biomedical maintenance process.

8. RECOMMENDATIONS

Based on the results obtained and the exhaustive analysis carried out, the following suggestions are presented aimed at strengthening the sustainability of Total Productive Maintenance (TPM) and ensuring the uninterrupted operation of the ICU mechanical ventilators:

First, it is advisable that the TPM be institutionalized as a permanent policy in the hospital, formalizing its pillars and procedures within the annual maintenance plan. Accumulated experience indicates that the systematic application of this methodology achieves significant improvements in availability, reliability and maintainability. Therefore, its continuity must be guaranteed through internal regulations and an organizational arrangement that supports its constant execution.

It is also essential to improve the technical skills of the personnel in charge of maintenance and those who operate the mechanical ventilators. It is recommended to establish continuous training programs that address topics such as autonomous maintenance, early detection of failures, analysis of indicators, safe handling of equipment and technical diagnosis. Continuous training will facilitate the preservation of the progress achieved and avoid the repetition of operational errors identified in the diagnostic phase.

Similarly, it is advisable to create a system for the monitoring and control of maintenance indicators, especially availability, MTBF and MTTR. The records Agudelo, M. (2021). Actualización de los protocolos de mantenimiento preventivo de los monitores de signos vitales y los ventiladores mecánicos pertenecientes al servicio de UCI de la Clínica León XIII. Obtenido de <https://bibliotecadigital.udea.edu.co/handle/10495/2242>

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of these indicators must be made on a weekly or monthly basis, which will allow detecting trends, predicting failures and making informed decisions. The use of standardized formats and appropriate software will help optimize the efficiency of analysis and improve the evaluation of the operational performance of the equipment.

Another important recommendation is to maintain and improve the preventive maintenance plan, ensuring that all scheduled activities are carried out in a timely and complete manner. It is essential that the maintenance area implements strict controls on the planning of tasks, compliance with established deadlines and the subsequent evaluation of the work carried out. To this end, it is suggested to use detailed checklists, standard operating procedures and monitoring mechanisms that reinforce technical discipline.

In terms of operational management, it is recommended to promote collaboration between healthcare staff and technicians, promoting co-responsibility in the care of mechanical ventilators. Effective communication between both parties will facilitate the notification of early failures, optimize technical service times and reduce the probability of operational errors that cause unnecessary interruptions.

In addition, it is suggested to ensure the availability of critical spare parts, specialized tools, and backup equipment, since late procurement of inputs can extend the MTTR and affect service continuity. Maintaining up-to-date inventory and proper purchasing planning can reduce wait times and avoid disruptions due to lack of supplies.

At the organizational level, it is recommended to establish rotation, rest, and work stress management programs for technical personnel, since fatigue was identified as an important cause in the diagnostic phase. Improving occupational health contributes to technical accuracy and the reduction of errors when handling biomedical equipment.

Finally, it is proposed to expand the implementation of the TPM to other essential biomedical devices in the hospital, such as infusion pumps, multiparameter monitors or defibrillators. The proven effectiveness of mechanical ventilators suggests that this approach has great potential to improve the functioning of the overall medical team and to raise the quality of service provided by the facility.

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