

Implementation of Tpm and Rcm to Increase Service Level in a Maintenance Sector Company

Juan Carlos Vasquez¹, Joaquín Gamarra², Edilberto Avalos-Ortecho³

^{1,2,3}Carrera de Ingeniería Industrial, Universidad de Lima, Perú

Av. Javier Prado Este 4600 – Santiago de Surco, Lima, Perú

20194707@aloe.ulima.edu.pe; 20194111@aloe.ulima.edu.pe; Eavalos@ulima.edu.pe

Abstract

Industrial maintenance management plays a critical role in operational continuity and efficiency in key sectors such as construction and mining. This study analyzes the impact of the joint implementation of Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM) in an industrial services company. A structured methodology was adopted, including the classification of critical equipment through ABC analysis and risk matrices, the use of Failure Modes and Effects Analysis (FMEA), and the planning of preventive tasks. The results show significant improvements in key indicators: Mean Time Between Failures (MTBF) increased by an average of 28%, Overall Equipment Effectiveness (OEE) improved from 40% to 65%, and the service level increased from 38% to 63%. Additionally, operational costs were reduced by 20%, optimizing equipment availability and strengthening operational sustainability. This study validates the effectiveness of TPM and RCM as complementary tools for optimizing maintenance processes, reducing failures, and enhancing competitiveness. The findings highlight the importance of integrating preventive and predictive strategies to face the challenges of industrial maintenance in dynamic environments.

Keywords

Total Productive Maintenance (TPM), Reliability-Centered Maintenance (RCM), Mean Time Between Failures (MTBF), Overall Equipment Effectiveness (OEE), Industrial Maintenance Management.

1. Introduction

The industrial maintenance service sector has experienced sustained global growth, driven by the demand for solutions that ensure operational continuity in critical industries such as mining and construction. In this context, innovations such as digitalization, predictive maintenance, and strategies like Total Productive Maintenance (TPM) have been implemented, achieving significant improvements. For example, Ahmad Hafidh Al Farihi et al. [1] report a 50% reduction in production defects and a decrease in unplanned downtime from 60 minutes to 20 minutes. Similarly, Rakyta et al. [13] report a increase from 72% to 82%, an 24% quality improvement, a 10–15% downtime reduction, and annual cost savings of €438,200.” In Peru, sectors such as construction grew by 13.2% in January 2024, emphasizing the importance of these strategies to optimize costs and ensure the operational continuity of plants and machinery, as reported by the Institute of Economic and Social Studies (IEES) [6]. Similarly, Braglia et al. [3] underline that using TPM and RCM increases asset availability and ensures a competitive service level.

The growing demand from industries for more reliable and cost-effective equipment has led to a constant search for innovative solutions in industrial maintenance. This includes the use of advanced technologies that allow real-time monitoring and failure prediction before they occur. These advances not only optimize operational processes but also help reduce costs and improve long-term productivity. According to Mallioris et al. [9], the implementation of predictive maintenance systems based on data analysis has proven to be one of the most effective strategies for improving equipment reliability and reducing unplanned downtime. Similarly, the use of digital platforms for maintenance management has allowed companies to improve operational efficiency and make informed decisions, directly impacting sector competitiveness.

Moreover, to offer a high level of service, it is essential that the equipment used in operations meets the necessary requirements to minimize failures and operate optimally. This ensures not only the reliability and availability of equipment but also service quality and competitiveness [14]. Ahmad Hafidh Al Farihi et al. Preventive maintenance is critical to ensuring the reliability and availability of equipment in the industry. The lack of adequate maintenance can lead to an increase in failure frequency, affecting service levels. The literature shows that implementing preventive maintenance programs reduces downtime, minimizes costs associated with unplanned failures, and contributes to improving quality and efficiency in the

service provided [3]. Moreover, maintenance not only aims to repair after a failure but, when performed preventively, can optimize the availability and reliability of equipment across various industrial sectors [9]. Pinto et al. [12] point out that these preventive and predictive strategies are key to meeting quality standards required in high-demand sectors. This study aims to assess how the joint implementation of TPM and RCM impacts the service level of a maintenance company, improving equipment reliability and availability. It is proposed that by optimizing failure management and reducing downtime, these methodologies can meet the required service standards, strengthening competitiveness and customer satisfaction. Currently, the company has a service level of 43.10% for cleaning, manufacturing, and welding services, and 12% for bolt elongation services.

To understand the relationship between maintenance and service level, it is crucial to analyze how effective management optimizes key indicators. Strategies like TPM and RCM improve equipment efficiency and reduce failures by analyzing operating patterns and failure modes of each component. These methodologies seek to maintain high operational reliability and meet service expectations [3]. Key indicators impacted by effective maintenance management include MTBF and OEE. Previous studies show that proper preventive maintenance significantly increases both indicators, reducing operational costs and downtime, which are essential for measuring and improving service levels as they reflect operational capacity and equipment efficiency [3]. Additionally, Sousa and Lopes [14] conclude that good maintenance planning not only improves these indicators but also ensures the operational and financial sustainability of companies.

2. Methodology

Using the Pareto tool, we identified the following main causes: the lack of maintenance leads to unexpected shutdowns, high costs, and a decrease in service levels. According to Ahmad Hafidh Al Farihi et al. [1], the implementation of TPM strategies significantly reduces unplanned downtime, increasing overall equipment efficiency (OEE). Mallioris et al. [9] highlight that effective predictive maintenance anticipates issues before they occur, minimizing associated costs. Furthermore, Braglia et al. [3] emphasize that the combination of TPM and RCM increases asset availability and reduces failures, also assert that proper maintenance management not only improves service levels but also aligns operational results with the company's strategic objectives.

To address these issues, a combined strategy of Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM) is proposed [3]. This integrated methodology not only reduces failures and improves availability but also optimizes resources through the preventive and predictive approach offered by both methodologies [3]. According to Braglia et al. [3], the combination of TPM and RCM is ideal due to the complementary nature of these methodologies. TPM seeks to improve overall equipment efficiency through autonomous and preventive activities involving all organizational levels [3],[7]. RCM, on the other hand, focuses on analyzing and prioritizing maintenance needs based on equipment criticality, enabling the establishment of preventive maintenance tasks based on the most critical failure modes [14]. Pinto et al. [12] report a 23–38% reduction in downtime and 16–38% fewer interventions, leading to improvements in Availability (+2%), MTBF (+14–21%), and OEE (+5 points).

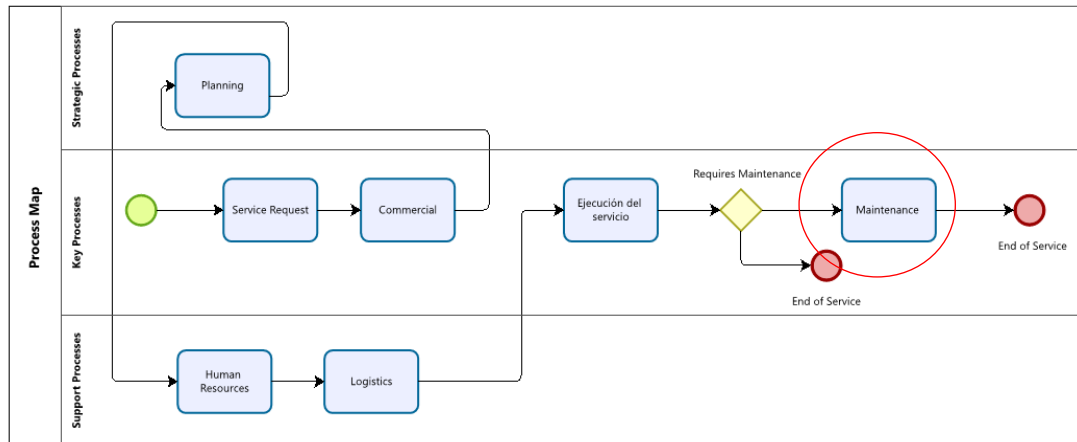


Fig. 1: Flowchart of the current process and problem determination.

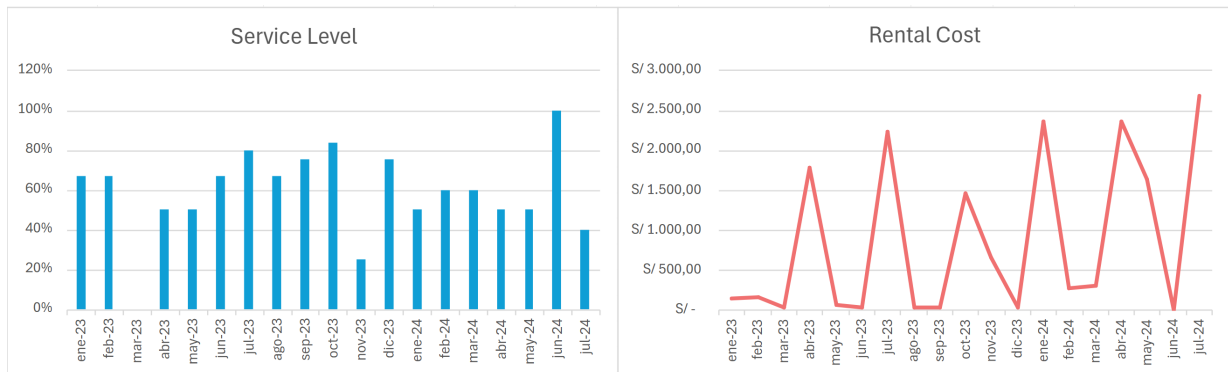


Fig. 2: Service level and rental cost charts for equipment replacement.

As shown in Figure 2, the service level was calculated using the following formula: (Service performed in good condition) / (Services performed)

The analysis reveals that service level values fluctuate during the years 2023 and 2024, with an average of 57.42%, indicating significant instability in performance. At the same time, rental costs show considerable increases in key months such as April 2023 (S/ 1,780), July 2023 (S/ 2,235), and July 2024 (S/ 2,685), due to the replacement of failed equipment. This highlights the importance of implementing effective maintenance strategies to stabilize service and reduce associated costs.

The implementation of this methodology follows structured steps, combining TPM and RCM for efficient integration. First, the selection and classification of critical equipment are carried out, where equipment is evaluated and classified according to its impact on production and criticality, Secondly, Braglia et al. [3]. Indicate, Failure Modes and FMEA is performed, identifying failure modes and their potential effects to define preventive maintenance tasks, following the RCM approach. It has been noted that the FMEA within TPM/RCM has been shown to reduce failures by 23–38% and repair time by 27–40% [12]. Third, the planning and execution of preventive maintenance are carried out, developing a plan based on FMEA to optimize resources and reduce downtime [3],[12]. It is suggested that adequate planning can improve OEE by ~10% and downtime reduced by 10–15%, with significant cost savings and reduce operational costs in the medium term, as indicated by Rakytá et al. [13]. Finally, continuous monitoring and improvement are performed, establishing a tracking system using indicators such as MTBF and OEE to evaluate and adjust maintenance [13].

For the modeling of the solution, Arena software will be used. To evaluate the problem and its potential improvement, an AS IS model will be developed, which represents the current behavior of equipment maintenance and associated failures. Process times were collected, and using the Output Analyzer, the distributions of each were determined, ensuring that they met the acceptance test values: Chi-square > 0.1 and Kolmogorov-Smirnov > 0.5.

For the TO BE scenario, which represents the proposed improvement, the same parameters were used. The implementation results will be analyzed using the following key indicators, evaluating both the AS IS and TO BE models to measure the impact of the improvements. Figure 3 shows the macro design of the solution.

- 1) Service level: (Services performed in good condition) / (Services performed)
- 2) OEE: Availability x Performance x Quality = (MTBF / MTBF + MTTR) x (Planned execution time / Actual execution time) x (Services performed in good condition / Services performed)
- 3) MTBF: (Operating time) / (Number of failures)
- 4) MTTR: (Repair time) / (Number of repairs)
- 5) Reliability: $R(t) = e^{(-\lambda t)}$
- 6) Availability: (MTBF) / (MTBF + MTTR)
- 7) Expected revenue: (Execution days) x (Rental cost per day)
- 8) Rental costs: (Days the machine failed) x (Rental cost)

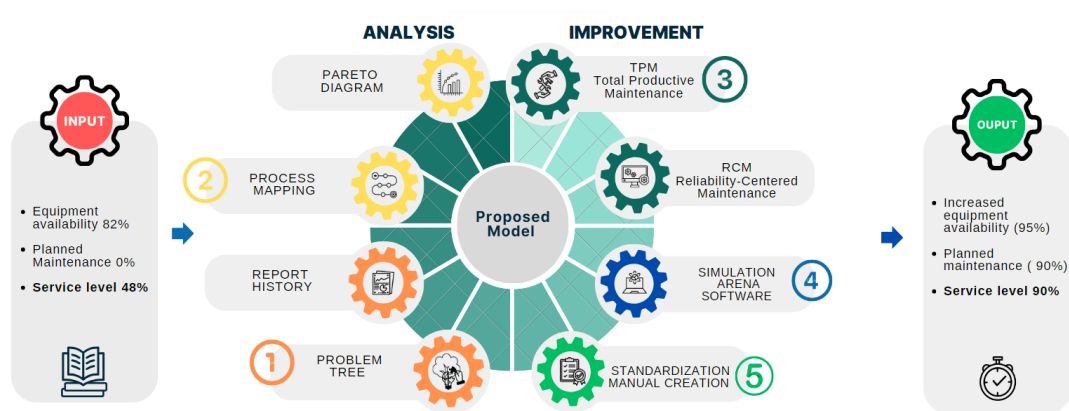


Fig. 3: Design of the macro solution

3. Results

The results of the classification of the company's equipment using tools such as RCM, risk matrix, and ABC analysis are shown below.

Table 1: Equipment Classification Results.

Equipment	Criticality	Unit
Hytorch Wrench 3 7/8"	High	1
Hytorch Wrench 3 7/2"	High	1
Hytorch Pump 10000 PSI	High	1
Hytorch Pump 10000 PSI	High	1
Angle Grinder 7	High	2
Angle Grinder 9	High	2
Welding Machine 220	High	2
Welding Machine 4410	High	2
Hydro Washer	High	1

Table 1, presents the classification of the equipment based on its criticality, using RCM tools such as the risk matrix and ABC analysis. These methodologies allow for prioritizing equipment based on its failure probability, impact, and economic relevance, optimizing resources, reducing costs, and improving reliability, especially for critical equipment or those associated with framework contracts [2], [12]. Based on the analysis of failure data and performance, key indicators such as MTBF, MTTR, availability, and reliability were identified, which are essential to prevent failures and ensure efficiency during services [13].

After evaluating the equipment, its behavior in selected services was simulated. This scenario, reflecting the actual system conditions, was referred to as "as is.", simulating current scenarios allows for the precise identification of optimal maintenance intervals. From this stage, the focus was on determining the optimal preventive maintenance time. To achieve this, the normal distribution was used along with the methodology proposed by Monchy, taking MTBF (Mean Time Between

Failures) as the reference. The goal was to establish a preventive maintenance interval that could prevent approximately 50% of failures. This percentage was selected because reducing the interval to δ -MTBF to prevent 84% of failures would have resulted in intervention times being too frequent, making maintenance both operationally and economically unfeasible [10].

The execution and behavior of the services were simulated in the ARENA software, structuring the process in three key stages. The first stage included initial activities such as quotation, planning, and resource allocation, where specific times were assigned to each entity through attributes for delays in the processes. Additionally, the required number of equipment was determined, including those prone to failure, those requiring rental, and the times associated with each task. In the second stage, hold modules were used to verify the availability of equipment in storage, and pickup modules were employed to group them according to requirements. Finally, the third stage used a decide module to classify services based on failures: equipment without failures was returned to storage, while failed equipment was sent for corrective maintenance or replaced by rented equipment. Throughout the process, record modules and variables in the assign module were used to track and manage key system indicators. This approach allowed for a detailed analysis of the impact of preventive maintenance, improving equipment availability and reducing associated costs.

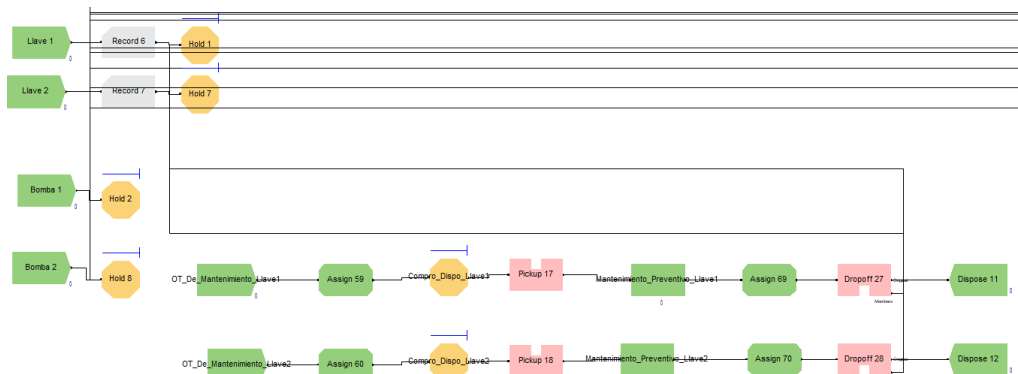


Fig. 4: Maintenance Improvement Model.

For the improvement scenario, maintenance plans were developed following the suppliers' recommendations. Additionally, using Monchy's maintenance approach, the optimal maintenance frequency for each piece of equipment was determined. As shown in Figure 4, equipment is withdrawn from storage to perform maintenance activities efficiently and as scheduled. The performance indicators for critical equipment in maintenance services are detailed in Table 2. To view the full simulation and scenarios of both the AS IS and TO BE models, please visit the following link: https://drive.google.com/drive/folders/1tiJBVRM_1Ins5jf9Arn17JemGnbCeTxs?usp=drive_link

Table 2: Performance Indicators of Critical Equipment (Wrench and Pump) in Maintenance Services.

Indicators	Unit	Wrench 3 7/8"	Wrench 3 7/2"	Pump 1	Pump 2
Availability	%	40.5	36	49	35.3
MTBF	Hour	137	66.3	143	78.6
MTTR	Hour	20.3	18.6	24.8	14.2
Utilized	Units	10.3	6.01	9.06	4.64
Failed	Units	2.76	2.57	2.7	1.27
Expected Revenue	S/.	49500	26400	52100	23700
OEE	%	19.4	11.8	21.7	11.6
Costs Incurred	S/.	15300	8340	9600	1820

Table 3: Service Level in the Bolt Elongation Process.

Indicators	Bolt Elongation Service
Service Level	38%

Table 4: Performance Indicators of Critical Equipment (Grinder, Welding Machine, and Hydro Washer).

Indicators	Unit	Grinder 7	Grinder 9	Welding Machine 220	Welding Machine 440	Hydro Washer
Availability	%	84.1	89.4	87.2	81.2	82.4
MTBF	Hours	244	301	254	211	243
MTTR	Hours	34	20.7	28.9	36.3	36
Utilized	Units	29	16.6	23.5	13	16.2
Failed	Units	8.86	4.45	6.65	4.06	5.39
Expected Revenue	S/.	5910	3210	14900	7250	36
OEE	%	48.5	51.3	49.9	36.5	44.3
Costs Incurred	S/.	640	279	1510	917	2750

Table 5: Service Level in Manufacturing, Cleaning, and Welding Services.

Indicators	Manufacturing, Cleaning, Welding Services
Service Level	52%

The service level of 38% reflects low operational capacity in the execution of the bolt elongation service, as shown in Table 3. The OEE indicators (Overall Equipment Effectiveness) for the wrenches and pumps are concerningly low, ranging from 11.6% to 21.7%, suggesting poor equipment usage due to a combination of low availability, low performance, and potential defects. The 3 7/8" and 3 7/2" wrenches have availabilities of 40.5% and 36%, respectively, which, combined with their high MTTR (20.3 and 18.6 hours) and low MTBF, significantly limit operational efficiency. The pumps show a similar situation, especially Pump 2, with an OEE of only 11.6%, indicating that it is almost non-operational most of the time.

Expected revenue amounts to S/. 151,700, but the rental costs for equipment replacement amount to S/. 35,060, which represents 23.11% of total revenue. This impact significantly reduces service profitability, as it not only affects revenue but also increases operational costs. To improve, more efficient preventive and corrective maintenance strategies must be implemented, along with a root cause analysis of availability and performance issues.

In the manufacturing, cleaning, and welding service, although the service level is 52%, the indicators show that it is still far from acceptable standards, as evidenced in Table 5. While availability values (between 81.2% and 89.4%) and OEE values (between 36.5% and 51.3%) are higher than in the bolt elongation service, they are still insufficient to achieve efficient performance. Availability should exceed 95%, and OEE should reach at least 84%. For example, the welding machines and hydro washer face significant issues: Welding Machine 440 has an OEE of 36.5% and an availability of only 81.2%, indicating prolonged downtime, while the Hydro Washer shows an OEE of 44.3%, reflecting inefficiencies in both availability and performance.

Expected revenue amounts to S/. 31,306, but rental costs for replacements amount to S/. 6,096, representing 19.47% of total revenue. Although this impact is lower than that of the bolt elongation service, it is still significant and reduces overall profitability. To reach a more competitive service level, it is recommended to optimize equipment usage with better planning strategies, reduce downtime through maintenance improvements, and train personnel to prevent recurrent failures.

Table 6: Performance and Profitability Indicators of Critical Equipment (TO BE Scenario)

Indicators	Units	Wrench 3 7/8"	Wrench 3 7/2"	Pump 1	Pump 2
Availability	%	41.3	39.9	19	2.17
MTBF	Hour	176	109	69.7	18.7
MTTR	Hour	19.6	15.5	9.09	5.25
Utilized	Units	9.39	5.86	8.07	4.34
Failed	Units	1.29	1.09	1.15	0.56
OEE	%	23.4	17.9	10.1	13.1
Expected Revenue	S/.	45300	26000	46600	21200
Costs Incurred	S/.	6870	3540	4040	813

Table 7: Service Level in the Bolt Elongation Process (TO BE Scenario).

Indicators	Bolt Elongation Service
Service Level	63%

Table 8: Performance Indicators of Critical Equipment (Grinders and Welding Machines) in the TO BE Scenario.

Indicators	Units	Grinder 7	Grinder 9	Welding Machine 220	Welding Machine 440	Hydro Washer
Availability	%	91.8	86.5	88.7	77.6	83
MTBF	Hours	519	522	537	320	475
MTTR	Hours	33.5	18.8	28.7	28.4	32.8
Utilized	Units	33.3	18.6	23.4	12.8	15.5
Failed	Units	5.05	2.34	3.26	2.06	3.64
OEE	%	67.6	63.1	63.2	44	37.6
Expected Revenue	S/.	6890	3650	14800	7300	10700
Costs Incurred	S/.	366	151	724	462	1350

Table 9: Service Level in Manufacturing, Cleaning, and Welding Services (TO BE Scenario).

Indicators	Manufacturing, Cleaning, Welding Services
Service Level	79%

After implementing preventive maintenance, the indicators for the bolt elongation service improved significantly, as shown in Table 7. Failures in the equipment decreased, such as the Wrench 3 7/8", which decreased from 2.76 to 1.29, representing a 53.3% reduction. Availability also increased, as detailed in Table 6, from 40.5% to 41.3% for the Wrench 3 7/8" (+1.98%) and from 36% to 39.9% for the Wrench 3 7/2" (+10.83%). MTBF for the equipment also grew significantly: the Wrench 3 7/8" increased from 137 to 176 hours, which is an increase of 28.47%, while the Wrench 3 7/2" showed a 36.96% increase. OEE also showed important improvements: the Wrench 3 7/8" increased from 19.4% to 23.4%, which implies a 20.62% increase. These improvements led to a service level increase of 65.78%, from 38% to 63%.

In financial terms, equipment rental costs decreased from S/ 35,060 to S/ 15,263, representing a savings of 56.47%. This savings maximized net revenue and improved service profitability, consolidating the importance of preventive maintenance for optimizing operational costs and ensuring a higher service level.

In the manufacturing, cleaning, and welding service, preventive maintenance generated outstanding results. This can be observed in Table 9, where the service level improvement is evident. Failures decreased significantly, such as in the Grinder 7, which decreased from 8.86 to 5.05, as indicated in Table 8, representing a 43.01% reduction, while in the Hydro Washer, failures were reduced from 5.39 to 3.64, a 32.46% drop. Equipment availability also improved: Grinder 7 increased from 84.1% to 91.8% (+9.16%) and the Hydro Washer from 82.4% to 83% (+0.73%). MTBF showed remarkable growth; for example, Grinder 7 increased from 244 to 519 hours, a 112.70% increase, while the Hydro Washer increased its MTBF by 95.06%. OEE also improved considerably: Grinder 7 increased from 48.5% to 67.6%, which is a 39.38% improvement. These improvements raised the service level from 52% to 79%, a 51.92% increase, consolidating a more efficient and effective operation.

In financial terms, rental costs were reduced from S/. 6,096 to S/. 3,053, which represents a 50% reduction. This savings, combined with the improvement in equipment efficiency, allowed for increased net service revenue and strengthened profitability. This demonstrates how preventive maintenance not only increases service levels but also optimizes the financial performance of the operation.

3. Discussion

When analyzing the indicators before and after the implementation of improvements, it is clear that the initially required minimum objectives, such as availability greater than 95% and an OEE of at least 84%, were not achieved. However, these results reflect that reaching such standards is not an immediate process. As the methodology states, it is based on a continuous improvement approach [12], [13]. Before the improvements, the equipment faced very short MTBF times, significantly limiting the ability to handle a higher number of failures without compromising availability. Equipment with low MTBF often presents a critical challenge to maintaining optimal operating levels [13]. Attempting to address more failures in this initial state would have reduced the equipment availability to critical levels, leading to more time spent in the workshop than in services, directly affecting operability and revenue [3]

4. Conclusion

The implementation of Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM) in a maintenance company demonstrates significant improvements in reducing downtime, increasing asset availability, and enhancing operational efficiency. According to previous studies, RCM maximizes the reliability and availability of equipment by prioritizing well-structured preventive maintenance [3], [12]. Additionally, the synergy between TPM and RCM not only reduces failures but also fosters a collaborative approach within organizations, ensuring that availability and reliability objectives are achieved through the involvement of all organizational levels [3]. This analysis confirms that the work addresses a significant technical gap, optimizing operational costs and aligning the outcomes with the company's mission.

References

- [1] S. A. H. Al Farihi, S. Sumartini, y L. Herdiman, "Designing Lean Maintenance Using Total Productive Maintenance Method – A Case Study at Wiring Harness Production," *E3S Web of Conferences*, vol. 465, p. 02016, 2023.
- [2] A. Al-Refaie and H. Almowas, "Multi-objective maintenance planning under preventive maintenance," *Journal of Quality in Maintenance Engineering*, vol. 29, no. 1, pp. 50–70, 2023.
- [3] M. Braglia, D. Castellano, and M. Gallo, "A novel operational approach to equipment maintenance: TPM and RCM jointly at work," *Journal of Quality in Maintenance Engineering*, vol. 25, no. 3, pp. 388-403, 2019.
- [4] S. Castañeda, D. Aranda, y S. Rodríguez, "Enhancing Machinery Availability in a Food Company: An Integrated Approach Using TPM, SMED, and RCM Methodologies," *SSRN Electronic Journal*, 2023.
- [5] R. Dekker, "Applications of Maintenance Optimization Models: A Review and Analysis," *Reliability Engineering & System Safety*, vol. 51, no. 3, pp. 229-240, 2019.
- [6] IEES, "Informe sobre el Crecimiento del Sector de la Construcción en Perú, enero 2024," *Instituto de Estudios Económicos y Sociales*, 2024.
- [7] M. Jasiulewicz-Kaczmarek and A. Gola, "Maintenance 4.0 Technologies for Sustainable Manufacturing," *Procedia Manufacturing*, vol. 38, pp. 715-722, 2016.
- [8] K. Krachangchan and N. Thawesaengskulthai, "Loss time reduction for improve Overall Equipment Effectiveness (OEE)," 2018 5th International Conference on Industrial Engineering and Applications (ICIEA), Singapore, 2018, pp. 396-400
- [9] P. Mallioris, E. Aivazidou, and D. Bechtsis, "Predictive maintenance in Industry 4.0: A systematic multi-sector mapping," *CIRP Journal of Manufacturing Science and Technology*, vol. 50, pp. 80–103, 2024.
- [10] F. Monchy, "Maintenance: Méthodes et Organisations", Paris, France: Masson, 1990.
- [11] S. Nakajima, *Introduction to Total Productive Maintenance (TPM)*, Cambridge, MA: Productivity Press, 1988.
- [12] G. Pinto, F. J. G. Silva, A. Baptista, N. O. Fernandes, R. Casais, and C. Carvalho, "TPM implementation and maintenance strategic plan – A case study," *Procedia Manufacturing*, vol. 51, pp. 1423-1430, 2020.
- [13] M. Rakyta, P. Bubenik, V. Binasova, G. Gabajova, and K. Staffenova, "The Change in Maintenance Strategy on the Efficiency and Quality of the Production System," *Electronics*, vol. 13, no. 17, p. 3449, 2024.
- [14] M. Sousa and I. S. Lopes, "A methodology for selecting and defining maintenance tasks for critical equipment," *Safety and Reliability – Safe Societies in a Changing World*, pp. 717-718, 2018.