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Service Level Improvement through TPM and EOQ Model in a Fumigation Company

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Abstract

The environmental sanitation company analyzed in this study experiences service interruptions caused by equipment failures and stockouts, within a context in which the global average service cancellation rate reaches 31.9%, according to IBISWorld (2023). The objective of the study was to improve service level and operational continuity through the integrated implementation of Total Productive Maintenance (TPM) and an EOQ-based replenishment model with safety stock and reorder point for critical supplies. Methodologically, failures and cancellations were diagnosed, reliability indicators (MTBF, MTTR, and availability) were calculated, a preventive and autonomous maintenance plan was designed, and the EOQ, safety stock, and reorder point parameters were determined. The proposal was validated through dynamic simulation in Arena, using a statistically determined number of replications. The results show an increase in service level from 87.0% to 92.7%, an improvement in inventory compliance from 83% to 98%, and a reduction in stockouts from 4.11 to 2.92 per replication. The main contribution of the study is an integrated and replicable TPM–EOQ model, validated through simulation, for service companies that are highly dependent on equipment availability.

Keywords
Autonomous maintenance; Continuous improvement; Service level; MTTR; Training; EOQ; TPM; Environmental sanitation services.

1. Introduction
The environmental sanitation and pest control industry plays a strategic role in protecting public health, ensuring food safety, and maintaining the operational continuity of sectors such as agriculture, agro-exports, hospitality, manufacturing, and retail, by preventing infestations and regulatory sanctions that may generate significant economic losses. Globally, the pest control services market was valued at approximately USD 25 billion in 2023, with a projected compound annual growth rate of 5% through 2028 (Grand View Research, 2024), highlighting a sector in expansion and closely linked to the competitiveness of regulated production chains.

However, significant inefficiencies still persist. IBISWorld (2023) estimates an average service cancellation rate of approximately 31.9%, reflecting the sector's vulnerability to operational failures, logistical miscoordination, and insufficient resource management. The Peruvian company analyzed in this study, with 17 years of experience and a client portfolio composed of 90% industrial customers, reports a cancellation rate of 7.6% (40 canceled services) and a service level of 92.4%, compared to the 98% benchmark considered as the sector reference standard and shown in Figure 1, resulting in a technical gap of 5.6 percentage points in service level (Rentokil, 2022). In addition, in 2023 the company recorded 60 rescheduled services, equipment availability of approximately 50%, and a stockout rate of 17%, generating an annual economic impact of S/ 70,752 due to unperformed services and idle time.

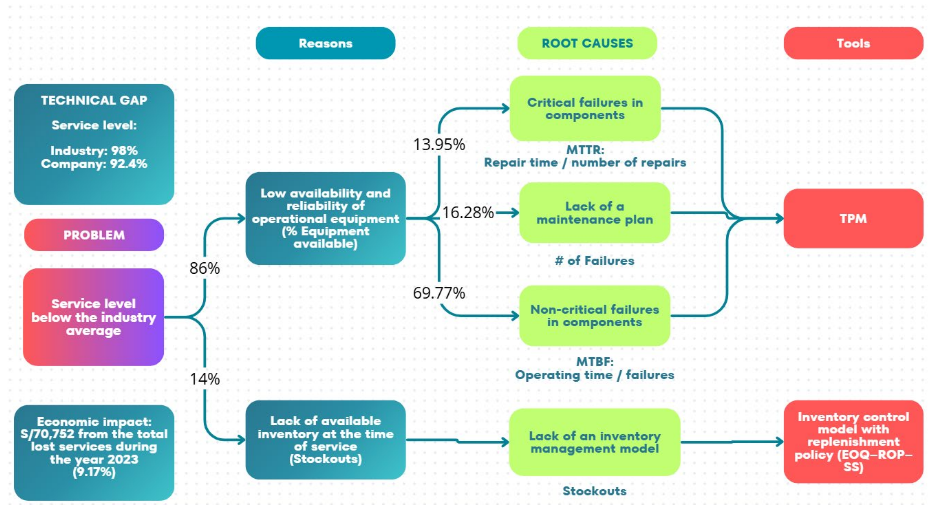


Figure 1. Problem Tree

From an academic perspective, although there is extensive literature on Total Productive Maintenance (TPM) and inventory models such as Economic Order Quantity (EOQ) in manufacturing contexts, a gap remains in their integrated application within environmental sanitation service companies, as well as in studies that jointly examine their effect on service level, equipment availability, and economic losses. Within this framework, the objective of this research is to design and validate an integrated model of TPM-based preventive maintenance and EOQ–reorder point–safety stock inventory management in order to increase equipment availability, reduce stockouts, and improve service level. The research question guiding the study is: how can an integrated TPM and EOQ model improve operational continuity and reduce the economic impact of cancellations and rescheduling in an environmental sanitation company?

1.1 Objectives

- To increase the company's service level through the implementation of effective maintenance strategies, as well as by optimizing inventory management under an inventory control model.
- To design and implement strategies aimed at significantly reducing the stockout rate, ensuring the timely availability of essential supplies for fumigation services and decreasing the incidence of cancellations caused by this issue.
- To implement maintenance tools in order to achieve greater equipment availability.
- To analyze the economic feasibility and sustainability of the implemented strategies by quantifying their results in terms of operational savings, reduction of costs associated with cancellations, and improvement in the company's overall profitability.

2. Literature Review

The literature on inventory management supports the use of the Economic Order Quantity (EOQ) model, reorder point (ROP), and safety stock as effective quantitative tools for reducing costs and ensuring the availability of supplies, even under irregular or intermittent demand. In a hardware and software company, the combined ABC–EOQ approach reduced holding and ordering costs, increasing profitability by 48% (Emar et al., 2021).

In a Peruvian metalworking company, the integration of Croston forecasting, simulation, and EOQ reduced inventory costs by 22.6%, while ensuring the supply of critical items (Jiménez Ayhuasi & Taquía Gutiérrez, 2023). Extensions of the EOQ model for deteriorating products or systems with backorders have shown that it is possible to satisfy up to 90% of unmet demand and minimize losses due to unrealized sales (Girija Bai et al., 2021; Patriarca et al., 2020), while hybrid ABC–XYZ approaches for sizing safety stock have reduced total costs by more than 15% while maintaining service levels above 95% (Demiray Kırmızı et al., 2024). Taken together, these studies show that EOQ, ROP, and safety stock can reduce stockouts by between 20% and 40% (Lok et al., 2022).

In parallel, the maintenance literature confirms that the adopted strategy has a direct impact on equipment availability and on indicators such as MTBF and MTTR. The combined application of TPM and Lean tools reduced non-contributory time by 25% in a construction company, increasing machinery availability and reducing delayed work orders (Cabrera et al., 2023), while a real-time model based on TPM, Lean, and Industry 4.0 achieved 88.6% availability in conveyor belts (Mendes et al., 2023).

In the energy sector, the integration of TPM with predictive maintenance increased MTBF, reduced MTTR, and improved the availability of critical assets (Fonseca Junior et al., 2017; Zúñiga et al., 2020). Other studies show that the transition from corrective to preventive maintenance can increase availability by 10% to 15% (West et al., 2024), and that the structured deployment of TPM raises productivity by 5% to 10%, reduces non-contributory time by 20–25%, and decreases human error by more than 70% (Reyes et al., 2018; Babaeimorad et al., 2024; Castro et al., 2024).

3. Methods

The proposed solution is grounded in the principles of continuous flow, adapted to the specific needs of an environmental sanitation service company. This approach seeks to minimize operational disruptions that lead to service cancellations or rescheduling, ensuring an efficient and synchronized process across all key stages. To achieve this, three elements are integrated: the application of Total Productive Maintenance (TPM) through a preventive and autonomous maintenance plan to increase the availability and reliability of fumigation sprayers; the implementation of a replenishment model based on EOQ, reorder point (ROP), and safety stock to ensure the timely availability of critical supplies; and the use of historical data on services, failures, and inventory consumption as inputs for calculating reliability indicators and inventory parameters. Finally, the proposal is validated through discrete-event simulation in Arena, which makes it possible to assess the combined impact of these tools on service level, stockouts, and operating times in a controlled and replicable environment (Figure 2).

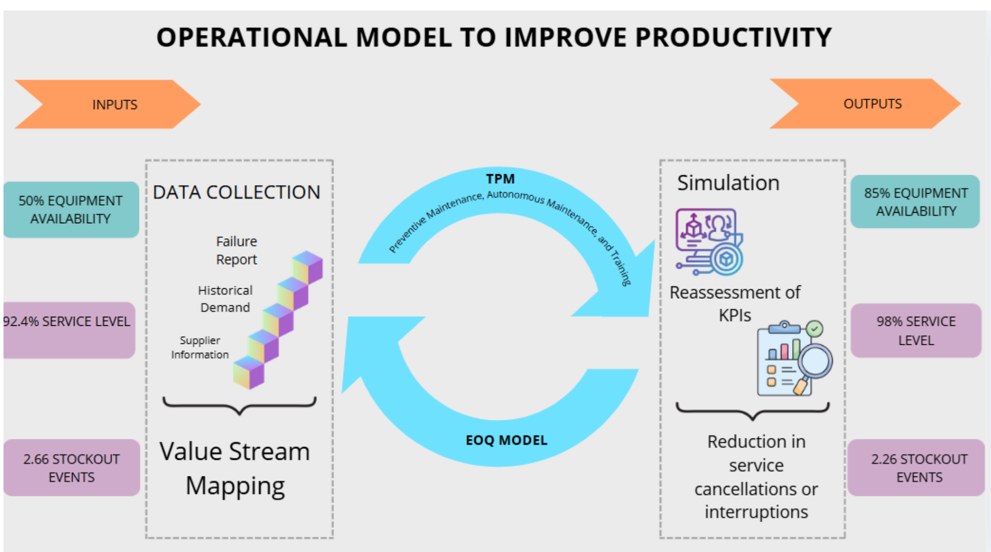


Figure 2. Operational Model to Improve Productivity

Total Productive Maintenance (TPM) will be used in this research as the main tool to increase the availability and reliability of fumigation equipment by reducing failures and downtime. Rather than being limited to corrective maintenance, a structured scheme based on three specific pillars will be implemented:

- **Preventive maintenanceo:** Maintenance frequencies and scheduled interventions will be defined according to MTBF and equipment criticality for inspection, cleaning, adjustment, and spare parts replacement, with the aim of reducing severe failures and lowering MTTR.
- **Autonomous maintenance:** Operators will take responsibility for basic daily tasks such as cleaning, lubrication, and visual inspection by following standardized checklists, allowing early detection of anomalies and preventing minor issues from becoming breakdowns that lead to cancellations or rescheduling.
- **Personnel training:** Training sessions will be developed for operators and technicians, focused on the proper use of equipment, execution of TPM routines, and completion of maintenance records, with the objective of improving maintenance discipline and the traceability of interventions.

Taken together, the implementation of these pillars is expected to increase equipment availability, reduce the frequency of failures during service execution, and directly contribute to improving the company's service level. A more detailed representation of their implementation is shown in Figure 3.

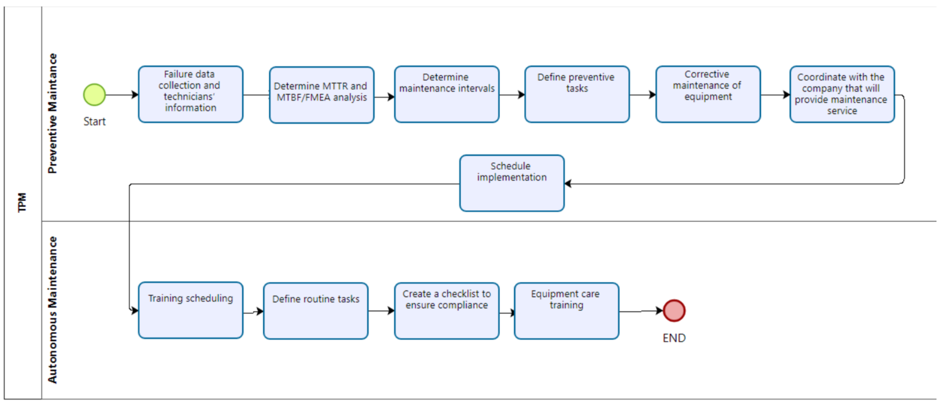


Figure 3. TPM Diagram

In parallel, an EOQ-based replenishment model is implemented. The process begins with the analysis of historical demand and supplier data, applying linear regression to forecast consumption. The Economic Order Quantity (EOQ) is then calculated by considering annual demand, ordering cost, and holding cost.

Based on this, safety stock is determined according to demand variability and lead times, and the reorder point (ROP) is established as the inventory level that triggers a new order.

$$SS = \sigma \times Z \times \sqrt{LT}$$

$$ROP = (DD \times LT) + SS$$

Subsequently, suppliers are contacted and evaluated through a criteria matrix considering punctuality, cost, and quality. After supplier selection, the EOQ model is implemented with continuous monitoring of inventory levels and demand fulfillment. Operational data are then collected to assess the effectiveness of the model and make adjustments to ensure its alignment with the company's efficiency and availability objectives. All of these elements are reflected in Figure 4 below.

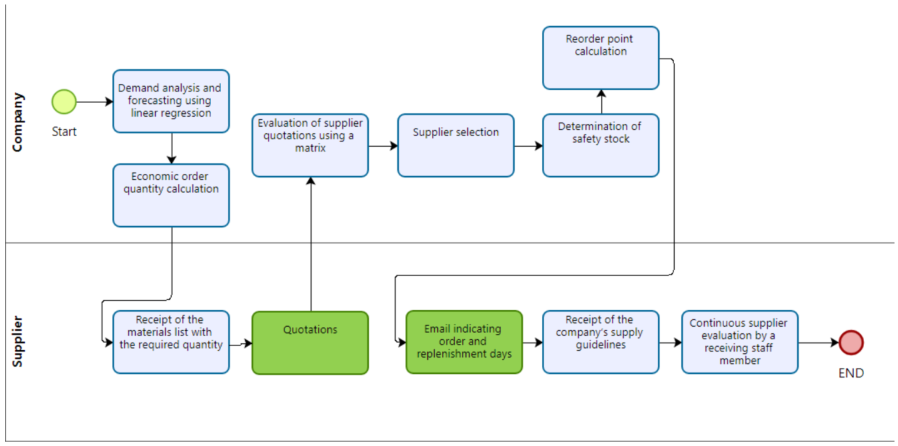


Figure 4. EOQ Replenishment Model Diagram

The main indicators considered for the development of this project are presented in Table 1.

Table 1. Performance Indicators

Indicator	**Formula**
Stockouts	Occurrences
Service Level	Services completed / Services scheduled × 100
MTTR	(Σ repair times) / (number of repairs)
MTBF	(Σ operating times) / (number of failures)

4. Data Collection

For this research, the unit of analysis is the fumigation service requests in a typical month, during which the company schedules an average of N = 44 visits per month. Since this is a finite and known population, the finite population sample size formula was applied:

$$n = \frac{(N.Z^2.p.q)}{((N-1).d^2+Z^2.p.q)}$$

Where:

- Using:
- N = 44 visits
- Z = 1.96 (95% confidence level)
- p = 0.5 (maximum variance)
- d = 0.05 (precision)

By substituting these values into the formula, a result of n = 39.57 is obtained, which is rounded to n = 40 service requests, thereby defining the sample size to be analyzed in order to adequately represent the company's operational behavior over a typical month.

The input data used for the analysis come from a comprehensive time study conducted in the company, in which the duration of the entire fumigation process was measured. In addition, two critical aspects were evaluated: the interarrival time of fumigation service requests and the travel time required for personnel and equipment to reach the locations where the service was to be performed, as shown in Table 2.

Table 2. Table of Times

Activity	Distribution	Expression
Interarrival Time	Uniform	UNIF (205, 489)
Fumigation Time	Triangular	TRIA (36, 222, 239)
Travel Time to and Return from Headquarters	Normal	NORM (40.5, 8,68)

In addition, historical data on failures, repair times, and stockouts will be used to establish the basis of the simulation model and to realistically adjust the reliability and inventory parameters obtained through the following formulas in Table 3.

Table 3. Table of Indicators

Indicator	**Formula**
Stockouts	Occurrences
Service Level	Services completed / Services scheduled × 100
MTTR	(Σ repair times) / (number of repairs)
MTBF	(Σ operating times) / (number of failures)

5. Results and Discussion

5.1 Numerical Results

For this study, a comparison was made between the base scenario and the improved scenario. Initially, a pilot run with 30 independent replications was conducted to estimate the variability of the service level. Based on those results, the final sample size was determined as 38 replications, ensuring a 95% confidence level and a maximum admissible error of ±2 percentage points. With this number of replications, the confidence intervals obtained from Arena were analyzed for each performance indicator, including service level, stockouts, average service time, and maintenance time. Subsequently, a comparative analysis of means was carried out using the paired t-test in Output Analyzer, taking the 38 replications as the basis for the comparative evaluation between both scenarios.

Regarding service level, a statistically and operationally relevant improvement was observed after the implementation of the proposed solution. In the base scenario, the average service level was 87.0%, with a 95% confidence interval ranging from 85.08% to 88.92%. After the intervention, the average increased to 92.7%, with a 95% confidence interval between 91.84% and 93.56%, with no overlap between the two ranges. The paired replication-by-replication analysis estimated a mean increase of 5.72 percentage points, with a 95% confidence interval of [3.41, 8.04], confirming the existence of a significant and consistent improvement, equivalent to an approximate relative increase of 6.6% compared to the initial level.

With respect to stockouts, in the initial situation the mean was 4.11 stockouts per replication, with a standard deviation of 2.17 and a 95% confidence interval of approximately 3.39 to 4.82. After the improvement, the mean decreased to 2.92 stockouts per replication, with a standard deviation of 1.05 and a 95% confidence interval within the range of [2.58, 3.27]. The paired t-test on the replication-by-replication differences yielded a mean reduction of 1.18 stockouts per replication, with a 95% confidence interval of [0.307, 2.06], implying a relative reduction of nearly 29% compared to the base scenario, accompanied by lower process variability.

Regarding average service time, the paired-replication design made it possible to isolate the effect of the intervention from the variability inherent to the simulation. The average time increased from 78.9 to 80.2 units after the improvement, while the standard deviation decreased from 1.20 to 0.669. The paired t-test indicated a mean difference of 1.31 units, with a 95% confidence interval between 0.94 and 1.67; therefore, the hypothesis of no change was rejected. Although this increase represents only about 1.7% relative to the baseline average, it is accompanied by a clear reduction in dispersion, suggesting a more stable and predictable process.

Finally, the analysis of average maintenance time showed a substantial improvement. In the base scenario, the mean was 3.95 units, with a 95% confidence interval between 3.27 and 4.63. After the intervention, the time decreased to 3.00 units, with a standard deviation of 0.192 and a 95% confidence interval between 2.94 and 3.06. The paired t-test estimated a mean difference of –0.947 units, with a 95% confidence interval of [–1.63, –0.26], indicating a reduction of approximately 24% in maintenance time. In addition, the coefficient of variation decreased from approximately 52% to about 6%, evidencing a much more stable and controlled maintenance process, with a direct impact on equipment availability (Table 4).

Table 4. Results of the Base and Improved Scenarios

Indicador	Base Scenario	Improved Scenario
Service Level	87%	92.7%
Stockouts	4.11	2.92
Average Service Time	78.9	80.2
MTTR	3.95	3

5.2 Graphical Results

In general terms, the process for providing a fumigation service operates as follows:

First, the client contacts the company and a technical visit to the site is scheduled. During this visit, the staff evaluates the areas to be treated and determines the type of service required. Based on this information, the company prepares and sends a quotation to the client; if the quotation is accepted, the service date is scheduled. To carry out the fumigation, operators, equipment (fumigation sprayers), and the necessary chemical supplies are assigned. If at any point it is detected that there are insufficient materials or that the equipment presents significant failures, the service may be canceled or rescheduled while the supplies are purchased or the equipment is maintained. When the service is performed without incident, the operators complete the fumigation as planned and, finally, the company issues a certificate confirming the proper execution of the work, thereby concluding the process.

As mentioned above, the validation of the implementation was simulated in Arena software, where our model is shown in the following Figure 5:

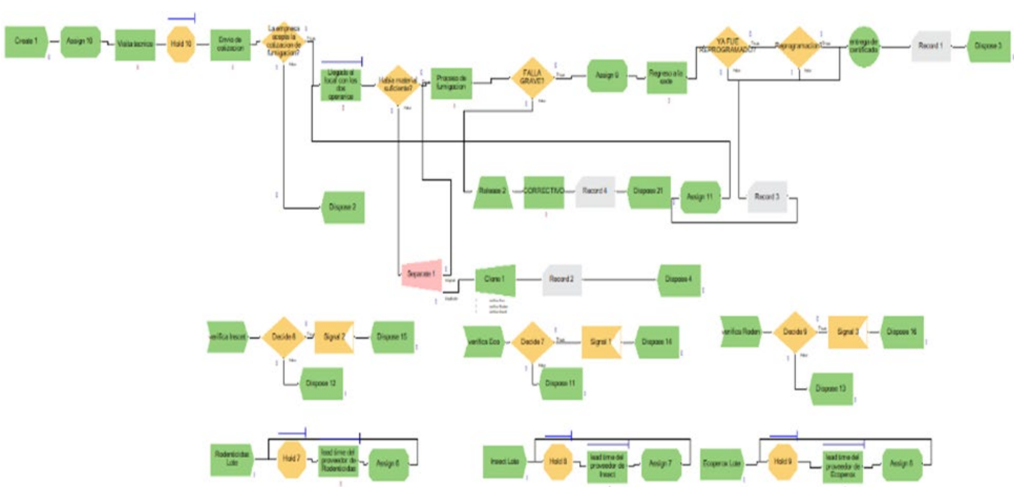
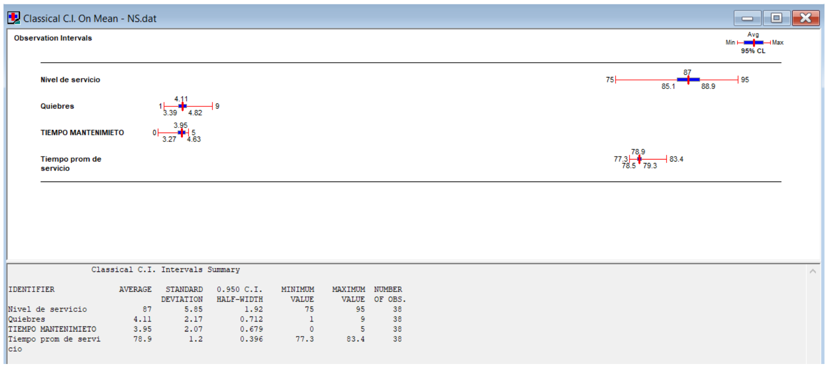


Figure 5. As-Is Model

The results obtained from the base model were processed using the Output Analyzer tool in Arena software, from which the statistical indicators used for the comparative analysis presented in the numerical results were obtained, based on the Figure 6 showing the base model results.



IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Nivel de servicio	87	5.85	1.92	75	95	38
Quiebres	4.11	2.17	0.712	1	9	38
TIEMPO MANTENIMIETO	3.95	2.07	0.679	0	5	38
Tiempo prom de servicio	78.9	1.2	0.396	77.3	83.4	38

Figure 6. Graphical Results of the Base Model

These results were obtained from a simulation whose stopping criterion was the completion of 40 services; that is, the model was run until that number of service requests was completed. Likewise, the use of 38 replications as the sample size for the statistical analysis of the indicators was validated.

5.3 **Proposed Improvements**

The improvement proposal integrates the application of Total Productive Maintenance (TPM) and the Economic Order Quantity (EOQ) model, with the aim of increasing the technical reliability of the equipment used in fumigation services and ensuring the continuity of critical material supply. Both approaches were selected due to their complementarity, as they simultaneously address the main sources of disruption identified in the initial diagnosis: recurrent operational failures and inventory stockouts. To quantitatively assess their impact, maintenance subroutines were incorporated into the simulation model and the order quantity in the replenishment scheme was adjusted; however, since this modification was made only at the quantity level, it was not necessary to alter the structure of the original model, as shown below in Figure 7.

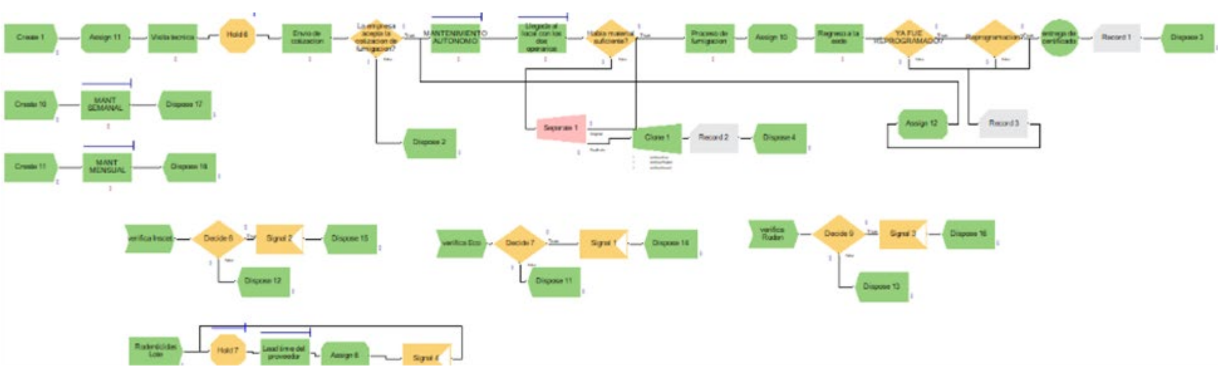
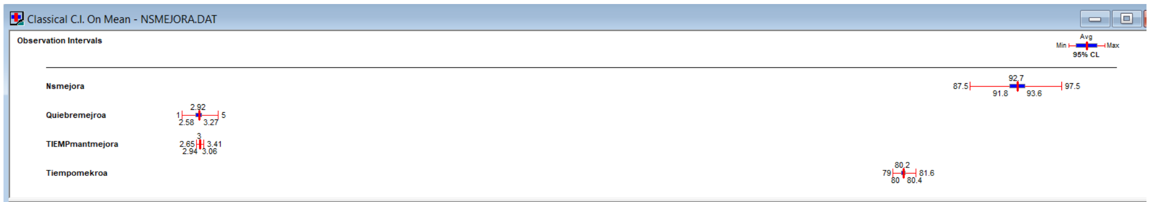


Figure 7. To-Be Model

After implementing the changes in the improvement model, the following results were obtained from the Output Analyzer, as shown in Figure 8.



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Nsmejora	92.7	2.62	0.863	87.5	97.5	38
Quiebremejroa	2.92	1.05	0.345	1	5	38
TIEMPmantmejora	3	0.192	0.0633	2.65	3.41	38
Tiempomekroa	80.2	0.669	0.22	79	81.6	38

Figure 8. Graphical Results of the Improved Model

Taken together, the simulation shows that the service level increased, stockouts per replication were significantly reduced, and average maintenance time decreased by approximately 24%, while average service time increased only marginally and with lower variability. These findings, compared with the initial scenario, demonstrate that the combined application of TPM improved equipment availability and reliability, whereas the EOQ model with reorder point and safety stock contributed to reducing inventory shortages. Overall, both tools improved the operational performance of the fumigation system by increasing service level and stabilizing the process without generating significant negative impacts on service times.

5.4 Validation

The initial analysis compiled key operational data, including failure records, repair times, historical availability, and service interruption patterns. This assessment identified spark plugs, air filters, nozzles, and pressure pumps as the components with the highest failure frequency and the main drivers of service rescheduling and cancellations, revealing a predominantly corrective maintenance approach that negatively affected service continuity.Based on these findings, a technical evaluation of equipment behavior was conducted through the analysis of historical failures, component criticality, and repair times. Criticality matrices were developed, and preventive and autonomous maintenance routines were defined in line with TPM principles. These routines incorporated standardized inspections, functional checks, and autonomous tasks carried out by technical staff to increase MTBF and reduce MTTR, as shown in Figure 9.

The TPM proposal was then validated through simulation using real company data, considering indicators such as availability, maintenance times, and service continuity. The results showed reductions in failures, interruptions, and unproductive time, confirming the effectiveness of the preventive approach. In addition, technical specialists and operational staff validated the feasibility of the proposed routines, and the maintenance plan is presented in Figure 10.

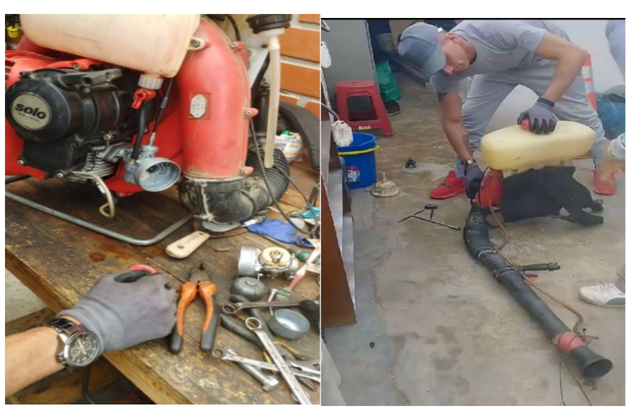


Figure 9. Preventive and Autonomous Maintenance


MANTENIMIENTO PROFESIONAL Y SANEAMIENTO AMBIENTAL S.A.C.

PROGRAMA DE MANTENIMIENTO DE MAQUINARIA

Figure 10. Maintenance Plan

In parallel with the failure analysis, warehouse data were examined and revealed discrepancies between actual demand and purchased quantities, which generated frequent stockouts of critical supplies such as rodenticides, Insect, and Ecoperox. These shortages caused delays, rescheduling, and cancellations, affecting service continuity and evidencing the absence of a formal inventory planning system adapted to operational variability.To address this issue, a replenishment model based on EOQ was developed, as shown in Figure 11, together with the calculation of the reorder point (ROP), safety stock, and ABC classification to prioritize the most critical supplies. The model also incorporated supplier lead time analysis to adjust inventory parameters and support timely replenishment during high-demand periods.

The EOQ proposal was evaluated through a comparative simulation between the current and improved scenarios. The results showed reductions in stockouts, supply variability, and costs associated with unplanned purchases. In addition, validation by operational staff and specialists confirmed the feasibility of the proposed parameters, demonstrating that EOQ strengthens inventory stability, improves service continuity, and complements the operational improvements achieved through TPM.

Demanda anual en unidades	30	litros
Costo por pedido	14400	Sueldo del almacenero
Costo de manetenimiento anual por unidad	12240	costo del alquiler+pedidos
Q optimo	8.40	Litros

Demanda anual en unidades	70	Kilos			
Costo por pedido	14400	sueldo del almacenero			
Costo de manetenimiento anual por unidad	12420	costo del alquiler+pedidos			
Q optimo	13	Kg	12740	Z	1.65

Ecoperox				
Demanda anual en unidades	20	Kilos		
Costo por pedido	14400	Sueldo del almacenero		
Costo de manetenimiento anual por unidad	12240	costo del alquiler+pedidos		
Q optimo	6.86	Kg	DESV	0.1

Figure 11. EOQ Calculation

6. Conclusion

The study results show that the integration of Total Productive Maintenance (TPM) and the EOQ inventory model significantly improved the operational performance of the fumigation system analyzed. The simulation with 38 replications confirmed that the service level increased from 87.0% to 92.7%, with no overlap in the confidence intervals, demonstrating a statistically significant improvement. This increase is associated with the simultaneous reduction of operational failures, greater technical availability of the equipment, and a decrease in inventory stockouts, all of which reduced cancellations and rescheduling while strengthening the operational continuity of the service.

In relation to inventory management, the application of the EOQ model with reorder point and safety stock reduced stockouts from 4.11 to 2.92 per replication, representing a relative reduction of nearly 29%. Likewise, inventory compliance increased from 83% to 98%, ensuring the continuous availability of critical supplies and eliminating the need for urgent purchases. The simulation also confirmed that the new replenishment scheme reduced variability and stabilized the operational flow, directly contributing to the improvement in service level.

With regard to the maintenance component, the implementation of TPM reduced average maintenance time by approximately 24% (from 3.95 to 3.00-time units) and significantly improved process stability, decreasing the coefficient of variation from 52% to 6%. These results indicate that the equipment operates for longer intervals without interruptions and that technical interventions are carried out more efficiently. The failure analysis confirmed a substantial reduction in critical events, validating the effectiveness of the preventive approach and the contribution of autonomous and standardized maintenance.

Overall, the study demonstrates that the combination of quantitative maintenance techniques (TPM) and analytical inventory models (EOQ–ROP–SS) constitutes an effective and replicable strategy for service companies that are highly dependent on equipment usage. The proposed solution increased reliability, improved availability, reduced system variability, and enhanced service level without requiring large-scale investments. Consequently, the study confirms that data-driven management, engineering modeling, and simulation-based validation are robust tools for transforming traditional processes into more efficient, predictable, and sustainable systems.

As a priority direction for future research, it is proposed to extend the TPM approach toward a Predictive Maintenance (PdM) scheme supported by sensors/IoT and data analytics, in order to anticipate failures and schedule interventions based on the actual condition of the equipment. In subsequent studies, this extension may be evaluated through controlled comparisons between traditional TPM and PdM, measuring their incremental effect on MTBF, MTTR, technical availability, and service level, as well as their impact on reducing unplanned downtime, cancellations, and operational variability. In addition, it is recommended to validate the performance of PdM over longer operating horizons and across more than one company in the sector, in order to determine its robustness and develop scalable adoption guidelines according to asset criticality, operational maturity, and budget constraints.

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