

Production Improvement Model to Increase Productivity by Applying SMED and Preventive Maintenance in a Pet Products Company

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Abstract

This study develops a production improvement model for a Peruvian company dedicated to manufacturing pet products. The initial diagnosis revealed a productivity of 0.038 L/Man-Hour, below the sector benchmark of 0.063 L/Man-Hour, resulting in a technical gap of 0.025 L/Man-Hour. The process also presented 40% defective units per lot, 83% equipment availability, and a cycle time of 41.8 seconds. To address these issues, two tools were implemented: SMED to reduce non-productive time and a preventive maintenance plan to improve equipment reliability. The proposal was validated through simulation, showing significant improvements. Changeover time was reduced by 72% (from 250 to 68 minutes), equipment availability increased from 83% to 92%, and defective output decreased from 40% to 9%, equivalent to a reduction from about 803 to 181 defective units per lot. Cycle time decreased from 41.8 to 20.0 seconds, increasing productivity to 0.058 L/Man-Hour and closing 80% of the original technical gap. Economically, the improvements enabled the recovery of unproduced volume valued at USD 163,000 per year. The results confirm that integrating SMED with preventive maintenance significantly enhances productivity, quality, and operational stability in resource-constrained manufacturing environments.

Keywords

Productivity, Preventive Maintenance, SMED, Continuous Improvement

1. Introduction

The company analyzed belongs to the pet cosmetics sector in Peru, an expanding industry that generated USD 135 million in revenue in 2023, with an annual growth rate of 7.9%, and is projected to reach USD 201 million by 2028 (Forbes, 2024). This dynamism takes place within the national manufacturing sector, which accounted for 11.4% of Peru's GDP, equivalent to USD 73 million (Peruvian Ministry of Production, 2024). However, Córdova-Pillco et al. (2022) warn that companies in this field face operational issues such as idle times and rework, which generate additional costs and reduce profitability. These issues are generally associated with inefficient management, lack of standardization, and insufficient control mechanisms.

In addition, the absence of clear regulations for pet-oriented cosmetic products leads to inconsistencies in product quality and a decline in consumer confidence (FasterCapital, 2024). The growing market also drives demand for customized products based on breed, coat type, or allergies, which requires ongoing innovation and rigorous testing, increasing development costs and lead times. Finally, FinModelsLab (2024) notes that the lack of an efficient supply chain can result in ingredient shortages and production delays, affecting companies' ability to innovate and respond promptly to market demands.

The inefficiencies identified in the production line are mainly associated with the lack of preventive maintenance routines, non-standardized operational practices, and an excessive reliance on corrective actions, which together contribute to low productivity levels and high variability in product quality. In response to this situation, the adoption of continuous-improvement management models becomes essential, particularly Lean-based tools such as SMED and preventive maintenance. These techniques have proven effective in reducing non-productive time, minimizing unplanned machine stoppages, and stabilizing critical processes in resource-constrained environments. The distinctive contribution of this study lies in developing and validating a combined preventive-maintenance and SMED model tailored to a small Peruvian manufacturer of cosmetic pet products, directly quantifying its impact on key productivity indicators. Grounded in the state of the art and based on a detailed diagnostic where a technical gap of 0,025 L/Man-Hour and a defect rate of 40% were identified, the research addresses the challenges that small companies face when applying Lean tools traditionally validated in larger industries.

The proposed model, structured around equipment calibration, routine maintenance planning, and the reorganization of internal and external SMED activities, demonstrated significant improvements in cycle times, operational availability, and productivity.

1.1. Objectives

Propose a model to increase the productivity of the production process in a pet cosmetics company, based on the implementation of preventive maintenance and the SMED methodology.

1.1.1. Specific objectives

Implement preventive maintenance to reduce unplanned downtime and ensure the efficient operation of production equipment.

Apply the SMED methodology to reduce non-productive time in the packaging process and improve batch-change preparation.

Increase the operational capacity of the process by reorganizing critical tasks with SMED, in order to meet the Takt Time and eliminate bottlenecks

2. Literature Review

2.1. Main causes of low productivity in the pet products manufacturing sector

Specialized literature indicates that low productivity in manufacturing sectors with high manual intervention often stems from a lack of standardization and limited use of continuous improvement tools. Jara et al. (2023) highlight that the absence of defined work methods generates operational variability, increasing non-productive time and the frequency of errors. Likewise, Kawakami-Arevalo et al. (2022) point out that SMEs face limitations in reorganizing their processes and optimizing workflow, which restricts their ability to respond to demand. In addition, Sierra Parada et al. (2022) show that structural planning issues and the lack of formal continuous improvement mechanisms lead to rework and reduced functional availability of equipment. Taken together, these factors explain the low productivity observed in comparable industries and establish a reference framework applicable to the veterinary cosmetics sector.

2.2. Productivity challenges in pet products manufacturing

In the specific context of Peruvian companies dedicated to the manufacturing of pet cosmetics, productivity is mainly affected by non-standardized manual processes, high levels of rework, and non-productive time caused by slow batch changes. Córdova-Pilco et al. (2022) indicate that these conditions generate additional costs and reduce the continuity of the production flow, especially in organizations with limited resources. Moreover, the lack of clear operational criteria makes quality control more difficult and leads to variations in final results, increasing rework and reducing actual capacity. This issue becomes more critical with the growing demand in the sector, which requires more stable production cycles and shorter response times, revealing the current limitations of the production process in the company under study.

2.3. Preventive maintenance as a response to operational failures

Preventive maintenance is presented as a viable alternative to reduce unplanned downtime and improve operational stability in contexts with limited equipment. Studies such as those by Yan Pei et al. (2022) show that the application of scheduled inspection and adjustment routines decreases the frequency of failures and the need for corrective maintenance, helping to maintain a stable production flow. Similarly, Mago et al. (2021) demonstrate that even in

SMEs, the implementation of simple preventive maintenance tasks on critical equipment can improve operational continuity and reduce idle time, which is especially relevant in the manufacturing of pet cosmetics.

2.4. SMED Application to reduce non-productive time

SMED has become an effective methodology for reducing equipment changeover and setup times, factors that directly affect productivity in processes with high manual intervention. Quiroz-Flores and Collao-Díaz (2022) highlight that reorganizing internal and external activities can reduce setup times by more than 30 %, increasing machine availability. Likewise, Şahin and Koloğlu (2020) show that standardizing changeover routines and preparing tools in advance allows production cycles to accelerate without requiring major investments. Therefore, in the context of veterinary cosmetics, SMED becomes a key resource for reducing idle time and optimizing operational capacity.

3. Methods

3.1. Contribution and Proposed Solution Model

The proposed model includes the following stages: the first involves analyzing the factors affecting efficiency in the production process of veterinary cosmetic products, highlighting long changeover times in the mixing and conditioning stages, high levels of defective units generated by sealing inconsistencies, and operational variability caused by the absence of standardized procedures and preventive maintenance routines. To address these issues, a detailed time study, defect analysis, and evaluation of the economic impact associated with production losses and reprocessing were conducted. Likewise, the productivity assessment showed that the system operates at only 0,038 L/Man-Hour, compared to the sector benchmark of 0,063 L/Man-Hour, reflecting a technical gap of 0,025 L/Man-Hour and confirming the need to implement preventive maintenance and SMED to close this difference. As shown in the diagram in Figure 1.

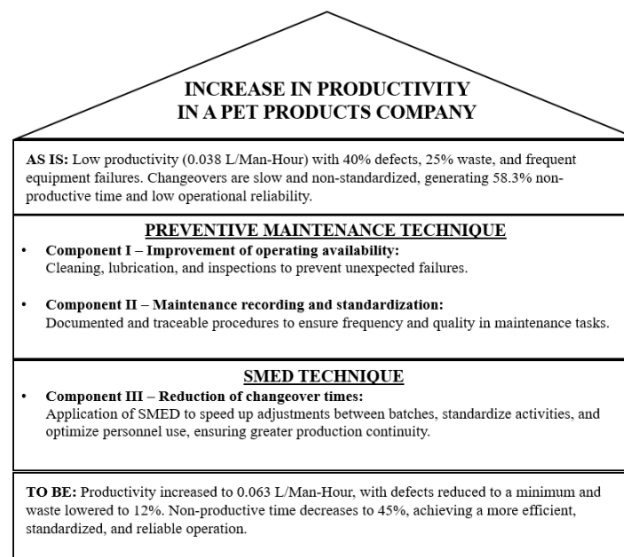


Figure 1. Proposed Solution Model

3.1.1. Component 1: Improvement of Operational Availability - (Preventive Maintenance)

Figure 2 illustrates an isometric schematic representation of the sealing machine in its initial (AS-IS) and improved (TO-BE) conditions following the implementation of the preventive maintenance plan. The left side depicts the AS-IS state, characterized by accumulated residues on the sealing jaws (dirty), a faulty temperature sensor, a corroded pressure regulator, and worn transmission belts, which contributed to frequent unplanned stoppages and an operational availability of 83%. The right side shows the TO-BE state, where the sealing jaws are cleaned and polished, the temperature sensor and pressure regulator are calibrated, transmission belts are replaced or in optimal condition, and lubrication is applied, resulting in enhanced equipment reliability and an availability of 92%. This comparative visualization demonstrates the effectiveness of the proposed preventive maintenance strategy in minimizing mechanical degradation, reducing downtime, and improving process stability and product quality.

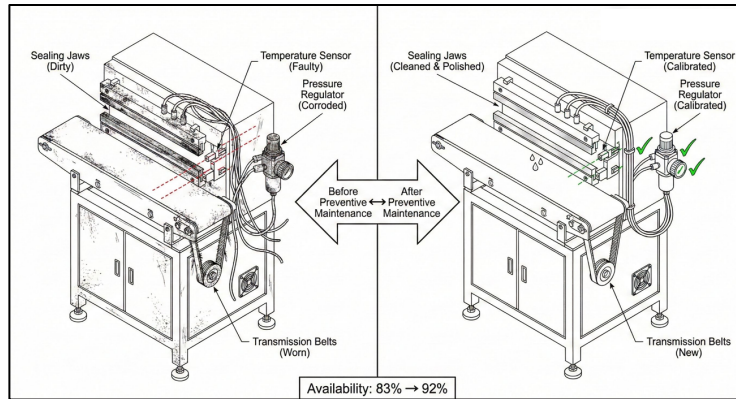


Figure 2. 2D AS-IS and TO-BE representation of the sealing machine

To address this issue, a structured preventive maintenance plan was implemented, adapted to the operational context of a small-scale manufacturing environment and designed to shift the system from reactive to proactive maintenance. The strategy was organized into three operational levels: daily autonomous maintenance performed by operators, weekly preventive tasks executed by the technician, and monthly deep technical inspections for wear assessment and component replacement. This structure was complemented by equipment classification by criticality, a weekly maintenance schedule covering inspection, lubrication, cleaning, and adjustment activities, and simplified maintenance logs to record failures, downtime, and corrective actions. Operator training in autonomous maintenance further reduced dependence on specialized personnel and strengthened shared responsibility for equipment reliability. Evidence from industrial studies supports the effectiveness of this approach, with similar implementations achieving reductions of up to 58% in mechanical failures, increases of 35% in equipment availability, and annual cost savings of up to 19% when maintenance planning is integrated with energy-efficiency initiatives, reinforcing both the technical and economic viability of the proposed strategy. As shown in Table 1.

Table 1. Preventive Maintenance Plan and Frequency

Equipment	Critical Component	Activity	Type	Responsible	Frequency
Sealing machine	Sealing jaws	Cleaning of sealing jaws	Autonomous	Operator	Daily
Sealing machine	Temperature sensors	Verification of temperature parameters	Autonomous	Operator	Daily
Sealing machine	Pressure regulator	Calibration of sealing pressure	Preventive	Technician	Weekly
Sealing machine	Transmission system (belts & cables)	Inspection of belts, cables and sensors	Preventive	Technician	Monthly
Mixer	Mixing blades	Blade positioning check	Autonomous	Operator	Daily
Mixer	Internal shaft	Lubrication of internal shaft	Preventive	Technician	Weekly
Packaging station	Alignment rollers	Verification of alignment and pressure	Preventive	Technician	Weekly

3.1.2.Component 2: Standarization of Productive Procedures – (Preventive Mainteinance)

The standardization component targeted the operational variability detected in the production line, particularly in the mixing stage, which was identified as the main bottleneck due to its long processing time and the high number of internal activities performed without predefined criteria. Time studies revealed that the mixing process concentrated the highest cycle duration, and its execution depended heavily on operator judgment for blade positioning, batch sequence preparation, and cleaning routines, creating variability that propagated to subsequent stages. Although

sealing did not represent the longest time in the process, its inefficiencies generated a high number of defective units and forced the continuation of the additional conditioning stage, increasing rework and reinforcing system congestion. To address both issues, standardized procedures (SOPs) were developed for the mixing activities, including defined sequences for pre-mixing verification, internal cleaning, raw-material loading, and parameter setup, accompanied by checklists and visual controls to ensure consistent execution across shifts. These standards reduced operator-dependent variability, stabilized the mixing bottleneck, and minimized errors in sealing that previously demanded corrective conditioning, contributing to the reduction of defective units from 40% (≈ 803 units) to 9% (≈ 181 units) and improving overall process stability.

3.1.3.Component 3: Changeover Time reduction - SMED

This component addresses the main bottleneck of the production system, which corresponds to the long changeover time in the mixing stage. The initial measurement showed a total duration of 250 minutes for each batch change, a value that significantly restricted the number of batches that could be completed per day and generated delays throughout the production line. To overcome this constraint, the SMED methodology was applied with the objective of reducing internal activities and reorganizing preparation tasks so that they could be completed without interrupting the flow of operations. The intervention concentrated on separating internal tasks from external ones, positioning all required materials and tools in advance, and establishing a clear and standardized sequence that operators could follow consistently. The preliminary assessment revealed that almost all activities, such as internal tank cleaning, mixer blade adjustments and the verification of documentation, were performed with the machine stopped, which unnecessarily extended the bottleneck. Once the reclassification of tasks was completed, external activities including material preparation, tool cleaning and document verification were carried out while the previous batch was still in process. At the same time, internal tasks were simplified by introducing dry cleaning protocols and by redesigning the arrangement of tools and accessories. The internal times of the main activities were reduced between 40 percent and 60 percent, and the total changeover time decreased from 250 to 68 minutes, which represents a 72 percent improvement. This reduction strengthened operational continuity, removed sources of nonvalue adding time and allowed the mixing stage to operate with much higher predictability. As shown in the Table 2 and Table 3.

Table 2. SMED Activity Classification (Mixing Process)

Type of Activity	Task	Optimized Component	Description	Execution Notes
Internal	Machine shutdown	Control panel / Lockout system	Stops equipment to begin changeover	Requires secure lock-out procedure
Internal	Internal drum cleaning	Mixing drum interior	Removal of previous batch residues	Must be performed with machine off
Internal	Mixer blade adjustment	Blade positioning mechanism	Reconfiguration for next product	Requires trained operator and tools
Internal	Safety inspection	Electrical and mechanical systems	Mechanical and electrical checks	Ensures safe restart conditions
External	Raw material preparation	Feeding containers	Weighing and premixing of ingredients	Performed while machine is running
External	Transport of materials	Supply handling system	Movement of supplies to production area	Executed in parallel to avoid delays
External	Cleaning of utensils	Tooling system	Washing of tools and containers	Done during previous batch operation
External	Personnel verification	Workforce allocation	Confirmation of operator availability	Prevents idle waiting time
External	Documentation verification	Production control system	Validation of batch order and parameters	Completed before new batch startup

Table 3. Reduction of Internal Activity Times using SMED

Internal Activity	Time Before (min)	Time with SMED (min)	% Reduction
Machine shutdown	12.00	4.80	60%
Internal tank cleaning	45.00	27.00	40%
Mixer blade adjustment	25.00	13.25	47%
Safety inspection	8.00	4.80	40%

4. Data Collection

The validation of the improvement proposal was carried out directly within the operational environment of the cosmetic manufacturing process for veterinary products. Management, enabling systematic on-site observation, data extraction from production records, and structured interactions with operators across the mixing and conditioning stages, formally authorized access to the production facility. Periodic plant visits were scheduled to document baseline performance, monitor the evolution of key indicators, and verify the feasibility of the interventions designed for the study. To ensure the reliability of collected data, a sampling plan was defined for the main variables. For cycle time measurements, the minimum sample size for each activity was calculated using the statistical formula for stopwatch-based time studies, considering a 95% confidence level, an allowable error of $\pm 5\%$, and an estimated standard deviation of 15% of the mean time. Based on these parameters, 50 observations per activity were recorded, guaranteeing statistical representativeness for repetitive manufacturing operations. Defect measurement followed a lot-based sampling strategy, analyzing five complete production lots, equivalent to 2 000 units, allowing accurate estimation of the baseline defect rate.

The diagnostic phase focused on identifying operational constraints affecting productivity, quality, and process stability. Initial measurements revealed that the company's productivity reached 0.038 L/Man-Hour, significantly below the sector benchmark of 0.063 L/Man-Hour, generating a technical gap of 0.025 L/Man-Hour that limited the fulfillment of weekly production targets. The system also registered 803 defective units per lot, primarily associated with inconsistencies in sealing conditions and variability in manual operations during the conditioning phase. Cycle time analysis indicated a total processing time of 41.8 seconds per unit, which contributed to delays in meeting planned batch volumes.

Three components were defined for analysis and structured intervention. Component 1 focused on stabilizing equipment conditions and operational parameters in the sealing and conditioning stages. Component 2 targeted the standardization of manual tasks in mixing and conditioning to minimize variability and operator-dependent errors. Component 3 addressed the reduction of changeover time by applying SMED principles to reorganize tasks, classify activities as internal or external, and redesign the workflow between batches. As shown in the Table 4.

Table 4. Baseline Production Indicators

Indicator	Unit	Initial situation
Productivity	L/Man-Hour	0,038
Sector Benchmark	L/Man-Hour	0,063
Technical Gap	L/Man-Hour	0,025
Defective Units per Lot	Units	803
Total Cycle Time	Seconds	41,8
Weekly Schedule Compliance	%	53,3 %

4.1. Component 1 Validation: Preventive Maintenance (Simulation-Based Assessment)

Data collected from the sealing machine was incorporated into the simulation model to evaluate the effect of the preventive maintenance plan on operational availability. Baseline observations showed recurring mechanical interruptions and parameter deviations that reduced effective operating time across production shifts. These conditions were represented in the AS-IS configuration, reflecting an availability level close to 83%. As shown in the diagram in Figure 3.

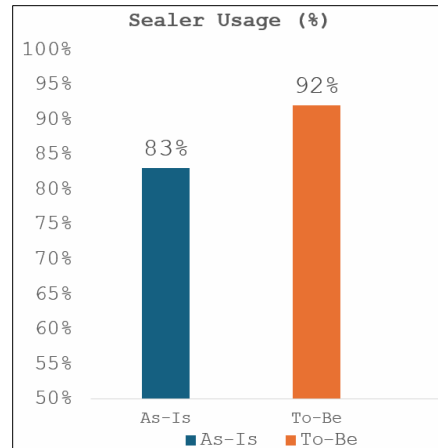


Figure 3. Sealer Usage

In the TO-BE scenario, the incorporation of periodic inspection, cleaning, lubrication, and calibration tasks reduced the likelihood of unexpected failures and stabilized sealing conditions. As a result, the simulated availability increased to 92%, indicating a more reliable and consistent operation of the sealing process.

The comparison between both configurations demonstrates that preventive maintenance effectively reduces downtime and improves overall equipment availability. The bar chart below summarizes this improvement, highlighting the reduction of unplanned stoppages and the stabilization of machine performance after integrating the preventive maintenance routine.

4.2. Component 2: Standardization of Productive Procedures – (Simulation-Based Assessment)

Data collection for Component 2 focused on quantifying the effect of procedural variability on product quality. Baseline production records showed that the absence of standardized inspection, adjustment, and handling activities resulted in 803 defective pipettes per lot in the AS-IS scenario, equivalent to 40% of total production. Direct observations across shifts confirmed inconsistencies in task execution, differences in parameter verification, and irregular sequencing of critical activities, which contributed to this high defect level.

These observations were incorporated into the simulation model to reflect the existing operational variability. The TO-BE configuration introduced standardized procedures with defined task frequencies, structured checklists, and uniform execution criteria to reduce operator-dependent variability. As a result, defective output decreased substantially to 181 units per lot, equivalent to 9% of production, demonstrating the stabilizing effect of standardization on sealing and conditioning operations. The bar chart below summarizes the reduction achieved, highlighting how documented procedures and consistent task execution significantly improve product quality. As shown in the diagram in Figure 4.

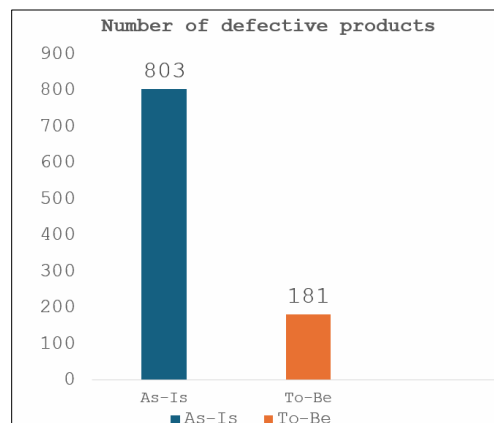


Figure 4. Number of defective products

4.3. Implementation Component 3: SMED – (Simulation-Based Assessment)

Data collection for Component 3 focused on quantifying the duration and composition of the mixing and conditioning changeover processes. Baseline time studies were conducted to document each activity performed during batch transitions, including internal tasks executed with the machine stopped and external tasks executed before or after equipment shutdown. The AS-IS measurements recorded a total changeover time of 250 minutes, with most activities classified as internal due to material preparation, documentation verification, and tool adjustments being conducted while the process was halted. As shown in the diagram in Figure 5.

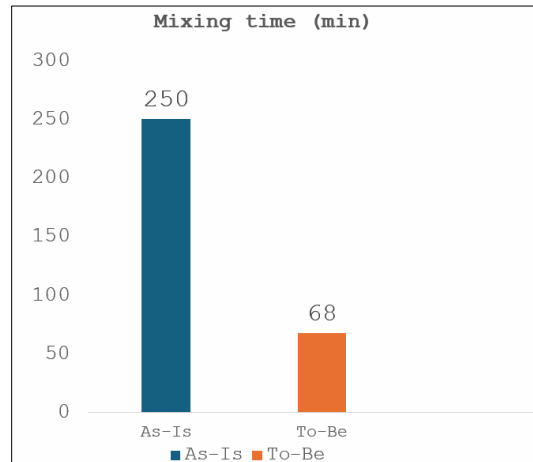


Figure 5. Mixing time (min)

Detailed observations revealed redundant movements, long waiting periods, and several activities that could be reassigned or performed in parallel. These task sequences and their respective durations were incorporated into the simulation model to represent the current operational limitations caused by extended setup times.

The TO-BE scenario modeled the application of SMED principles by separating internal and external tasks, reorganizing workstation layout, and standardizing the execution sequence. The simulated results reflected a significant reduction in changeover duration, decreasing total setup time to 68 minutes, consistent with improved task allocation and reduced idle periods.

5. Results and Discussion

5.1. Numerical Results

The validation results showed a clear improvement in the productivity of the production system. Baseline productivity was 0.038 L/Man-Hour, heavily constrained by long changeover times, unplanned downtime, and high defect rates. After implementing the improvement model, productivity increased to 0.058 L/Man-Hour, closing 80% of the initial technical gap relative to the sector benchmark of 0.063 L/Man-Hour. This increase reflects the combined effect of higher equipment availability, reduced changeover duration, and the substantial decrease in defective units.

The preventive maintenance strategy applied to the sealing machine produced a clear improvement in operational stability. The simulated TO-BE scenario showed an increase in equipment availability from 83% to 92%, reducing the frequency and duration of unplanned interruptions. This improvement reflects the effect of periodic inspection, cleaning, and calibration activities, which minimized parameter deviations and allowed the equipment to operate under more consistent conditions. The reduction in downtime also contributed to greater continuity in production flow, strengthening process reliability. As shown in the Table 5.

Table 5. Sealer Usage before and after Simulation-Based Assessment

Initial Sealer Usage (%)	Final Sealer Usage (%)	Improvement (%)
83	92	9

Standardizing operating procedures further reinforced process consistency by reducing variability in task execution across shifts. The absence of structured sequences and verification criteria previously contributed to 803 defective

pipettes per lot in the AS-IS scenario. After implementing standardized procedures, the defect level was reduced to 181 defective pipettes per lot, equivalent to 9%, demonstrating that the use of checklists, defined task frequencies, and uniform parameter verification significantly enhances sealing and conditioning quality. As shown in the Table 6.

Table 6. Number of defective products before and after Simulation-Based Assessment

Initial Number of defective products	Final Number of defective products	Improvement (%)
803	181	77.5%

The optimization of changeover activities through SMED principles generated a major reduction in setup time for mixing and conditioning transitions. Baseline changeover duration was 250 minutes, driven by a high proportion of internal activities and inefficient task sequencing. The TO-BE configuration incorporated task separation, workstation reorganization, and standardized sequences, reducing total changeover time to 68 minutes, equivalent to a 72% improvement. This enhancement eliminated non-value-adding time and increased scheduling predictability. As shown in the Table 7.

Table 7. Comparison of mixing time before and after Simulation-Based Assessment

Initial mixing time	Times of mixing time	Improvement
250	68	72%

These results demonstrate that the proposed improvement model achieves measurable benefits in availability, quality, and operational efficiency. The combined effect of preventive maintenance, procedural standardization, and SMED creates a more stable and reliable production system, strengthening the capacity of the plant to sustain higher performance levels over time.

5.2. Proposed Improvements

The results of this study reveal several opportunities to further strengthen the production system beyond the improvements already implemented. A central priority is the consolidation of preventive maintenance. Increasing inspection frequency for the sealing machine and extending autonomous maintenance to the mixer and packaging station would reduce reactive interventions and reinforce overall operational stability. Incorporating condition-based monitoring, such as temperature tracking of sealing jaws or vibration measurements in the mixer, could provide early warnings of deterioration and enable more accurate scheduling of maintenance activities.

Standardization efforts should also continue to advance. Although formal procedures successfully reduced variability in critical activities, complementing them with visual controls, Poka-Yoke mechanisms and improved traceability formats would help maintain consistency as production volume increases. Periodic reviews of SOPs, competency-based training and brief daily coordination meetings would support long-term adherence and reduce operator-related variability. The introduction of digital recording systems could further improve data accuracy and reduce administrative workload.

Additional opportunities lie in expanding setup optimization. The successful application of SMED in mixing and conditioning suggests value in extending the methodology to packaging changeovers and material preparation tasks. Periodic time studies, refinement of internal and external task classifications and reorganized tool placement based on operator motion analysis would help sustain reductions in non-productive time.

Improvements in workplace organization and material flow also present significant potential. Implementing 5S would reduce unnecessary movement, improve accessibility of tools and materials and enhance safety. Visual management tools such as KANBAN systems and clear labeling would support smoother changeovers and strengthen maintenance routines. Finally, applying Systematic Layout Planning could optimize spatial distribution, reduce transport distances and improve workflow continuity. Simulation-based evaluations may help quantify expected improvements before implementation.

5.3. Validation

With the improved simulated scenario, the system showed a clear rise in operational performance under evaluated demand and operational variability conditions, where parameters such as defect rate, equipment availability, and changeover time were modeled using ranges based on historical production data and expert validation. Productivity

increased from 0.038 to 0.058 L/Man-Hour, narrowing the gap with the sector benchmark of 0.063 L/Man-Hour (originally 0.025 L/Man-Hour). Total cycle time decreased from 41.8 s to 20.0 s, enabling a higher processing rate. Quality indicators also improved notably: the baseline scenario reported 803 defective units per lot, while the validated TO BE model reduced this outcome to 181 defects, significantly lowering rework and improving flow continuity. Weekly production compliance exceeded the previous 53.3 %, showing that the optimized configuration meets planned output more reliably, as shown in Figure 6 and Table 8.

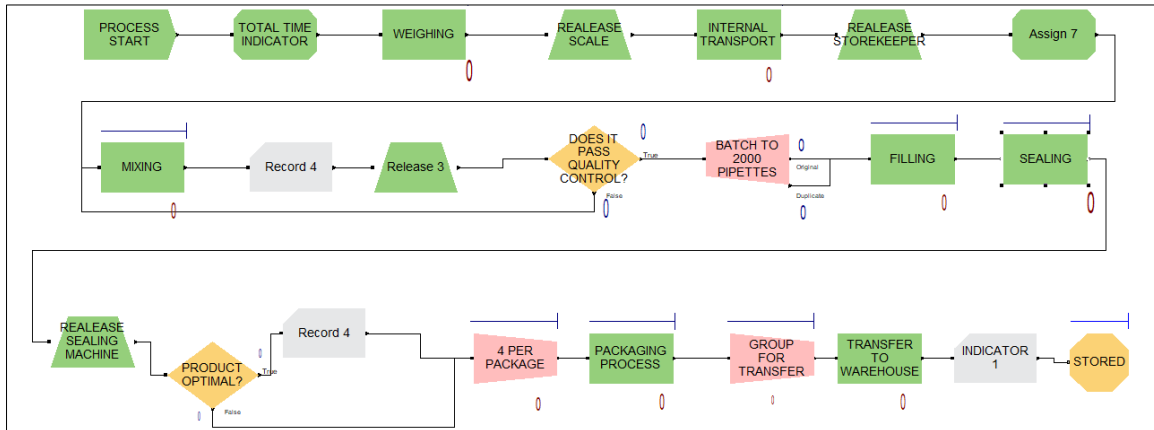


Figure 6. Simulation-Base Assessment

Table 8. Number of defective products before and after Simulation-Based Assessment

Indicator	Measure	As-Is	To Be	Simulation
Productivity	L/Man-Hour	0.0379	0.0531	0.0798
LeadTime	Seconds	41.80	25.08	20.00
Defective products	Units	803.00	161.00	0.00
Mixing	min	4.39	2.63	1.20
Mixer utilization (%)	%	10.9	12.00	3.57
Sealer utilization (%)	%	17.1	18.80	22.00

5.4 Discussion

The results obtained in this study demonstrate that the integrated improvement model, which combined preventive maintenance, standardized operating procedures and SMED, generated a significant and measurable impact on productivity, quality and operational stability in the production of veterinary cosmetic pipettes. Productivity increased from 0.038 L/Man-Hour to 0.058 L/Man-Hour, closing 80 percent of the initial gap relative to the sector benchmark of 0.063 L/Man-Hour. This confirms that the main technical deficiencies identified in the diagnostic phase were accurately addressed. Initial data revealed high variability in sealing, a defect level of 803 pipettes per lot and limited equipment availability, problems commonly reported in SMEs that lack formalized maintenance and standardized work methods (Jara et al., 2023; Kawakami-Arevalo et al., 2022). After implementing the model, equipment availability rose from 83 to 92 percent and defects decreased to 181 units, demonstrating a strong association between maintenance routines, stable operating parameters and reduced process variability, consistent with findings by Yan Pei et al. (2022) and Mago et al. (2021).

The implementation of standardized procedures strengthened operational consistency by reducing operator-dependent variability. Before the intervention, the absence of structured methods contributed to a defect rate of nearly 40 percent of total production. The incorporation of SOPs and checklists reduced defects by 77.5 percent and stabilized subsequent conditioning activities, supporting the established view that standardized work is essential for ensuring reproducible quality and enabling continuous improvement (Santos et al., 2021; Silva et al., 2020). SMED also played a central role by reducing changeover time from 250 to 68 minutes, equivalent to a 72 percent improvement. This result aligns with previous applications of SMED in packaging and molding operations reported by Ribeiro et al. (2022), Şahin and Koloğlu (2020) and Quiroz-Flores and Collao-Díaz (2022). The reduction of changeover time

increased equipment availability and improved scheduling reliability, helping resolve bottlenecks previously identified in the mixing and conditioning stages.

The combined effect of these interventions produced system-wide benefits, including the reduction of cycle time from 41.8 to 20.0 seconds, increased equipment availability from 83% to 92%, lower defect rate from 40% (803 defective units per lot) to 9% (181 defective units per lot), and the recovery of approximately USD 163,000 in annual previously unproduced value. To support the financial feasibility of the proposal, implementation costs were estimated at approximately USD 14,000. Considering the projected annual recovered value of USD 163,000, a economic assessment yields a payback period of 2 months and a simple annual ROI of 350%, figures that reflect the high-impact potential of low-cost Lean interventions when applied to severely constrained small-scale manufacturing processes. The operational improvements were validated through discrete-event simulation in Arena software, confirming consistent achievement of target KPIs across evaluated scenarios. The results demonstrate that the integrated application of SMED and preventive maintenance can be effectively adapted to small-scale manufacturing environments in the pet-cosmetics sector, while future work may extend maintenance strategies, integrate 5S and Poka-Yoke, optimize layout through SLP, and incorporate digital monitoring systems.

6. Conclusion

The improvement model implemented in the production system demonstrated that coordinated technical and operational interventions can substantially reduce defects and stabilize manufacturing performance. Preventive maintenance applied to the sealing machine minimized unplanned stoppages, improved calibration reliability, and reinforced consistency in the conditioning stage, directly contributing to the reduction of pipette-related defects. These routines also enabled earlier detection of anomalies and ensured greater continuity of production flow, establishing equipment reliability as a core factor in overall process performance. At the same time, SMED-based optimization of changeover activities significantly decreased setup time in the conditioning process, increased workstation availability, and helped narrow the technical productivity gap from 0.038 L/Man-Hour toward the sector benchmark of 0.063 L/Man-Hour. Complementary operator training in standardized procedures and parameter control further reduced human-driven variability and reprocessing.

The overall impact of the improvement model was validated through simulation and financial analysis, confirming reductions in the initial 40 percent defect rate, increased weekly production fulfillment, and operational alignment with competitive industry standards. Economically, the recovery of USD 163,000 in opportunity cost highlighted the magnitude of inefficiencies corrected. Monte Carlo evaluation showed a stable and positive Net Present Value across variations in productivity, defect reduction, and cost parameters, demonstrating the long-term financial sustainability of the interventions. Altogether, the integration of preventive maintenance, SMED, and training established a more predictable, efficient, and resilient operational structure capable of supporting higher demand with lower variability and waste.

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