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Improving Production Efficiency in a Chocolate SME through Continuous Flow, SMED and Poka-Yoke

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Abstract

Operational efficiency in Peruvian chocolate SMEs remains limited despite a sector benchmark approaching 75%. Artisanal plants continue to face recurring failures such as thermal variability during tempering, inaccurate filling of buffer tanks, reprocessing in molding, and excessive changeover times that compromise product quality and restrict productive capacity. The plant analyzed in this study operates at only 39.28% real efficiency, evidencing structural gaps in flow synchronization, standardization, and control of critical variables. The main contribution of this research is the formulation of a low-cost, high-impact Lean improvement model specifically tailored to artisanal chocolate manufacturing, addressing a methodological gap in the literature that traditionally focuses on highly automated plants. This integrated model combines SMED, Poka-Yoke, and Jidoka-based continuous flow to reduce operational variability and enhance process stability in low-automation environments. The model was subsequently validated through time–motion studies, pilot testing, and discrete-event simulation with 30 replicates per scenario, confirming substantial improvements: transfer time reduction (180 to 44 min), decreased tank-level variability (20% to 5.5%), reduced reprocessing (25% to 5%), and an increase in overall efficiency to 75%.

Keywords
Efficiency, Chocolate industry, SMED, Poka-Yoke, Jidoka

1. Introduction
Chocolate production has become an increasingly important activity for small and medium-sized enterprises due to the growing demand for premium, origin-certified, and artisanal products. As consumers increasingly seek higher-quality chocolate, manufacturers face growing pressure to improve productivity, maintain consistent product quality, and remain competitive in a rapidly evolving market. The chocolate industry has experienced growing interest in premium, functional, heat-resistant, and quality-oriented products, creating increasing pressure for manufacturers to improve process stability and product consistency (Qi et al., 2025) . Despite this positive trend, small and medium-sized chocolate enterprises (SMEs) continue to operate with low productivity and high process variability this represents a critical gap, considering that Peruvian MIPYME reports consistently highlight productivity limitations, structural gaps, and the need to strengthen competitiveness among small and medium-sized enterprises (Ministerio de la Producción del Perú, 2023). In contrast, many artisanal plants report efficiencies below 40%, caused by discontinuous material flow, inadequate thermal control, and high dependence on manual operations. Comparative studies in food-processing SMEs highlight recurrent operational deficiencies such as unstable flow, excessive changeover times, and decision-making based on subjective criteria. Flores Pérez et al. (2023) showed that inefficient plant layout and unnecessary material transfers contribute to productivity losses and operational bottlenecks in SME production environments. In the specific case of chocolate production, rheological sensitivity to temperature makes the process highly vulnerable to operational deviations: the viscosity temperature dependency reported by Kumbár et al. (2021) and the influence of refining conching conditions on

chocolate quality, flow behavior, and process performance (Valverde-Ayllon et al., 2022) underscore the need for precise control mechanisms in artisanal chocolate production.

Previous studies have evaluated the application of Lean tools in food-processing environments. SMED has shown potential to reduce changeover times and improve operational efficiency in food-sector production lines (Barbieri-Silva et al., 2022; García-García et al., 2022; Mariluz-Cuadros & Minaya-Sanchez, 2025), while visual management tools have proven useful for improving information visibility, supporting operational communication, reducing waste, and strengthening productivity in production environments (Brunelli et al., 2025; Mielczarek, 2024). Likewise, Poka Yoke mechanisms have been validated as effective solutions for reducing human error, guiding operators during manual tasks, and improving process efficiency in production environments (Trojanowska et al., 2023). Moreover, Lean practices have begun to be explored within food and chocolate SMEs, but studies emphasize that these companies face infrastructure, training, and resource limitations that may hinder implementation (Quevedo Olaya,J.L.,2024; Matindana & Shoshiwa, 2025). However, the existing literature presents a significant methodological gap. While prior work evaluates SMED, visual management, or continuous-flow concepts individually, no study has simultaneously integrated SMED, Poka Yoke, and Jidoka based continuous flow into a cohesive operational model tailored to the specific constraints of artisanal chocolate production. Furthermore, most referenced implementations have been tested in medium or highly automated factories, making them poorly aligned with the manual, thermally sensitive, and resource-constrained nature of Peruvian chocolate SMEs. This research addresses this gap by proposing and validating an integrated Lean improvement model specifically designed for low-automation chocolate production environments. By combining SMED, Poka Yoke, and Jidoka based continuous flow, the study introduces a low cost, high impact solution aimed at reducing variability, stabilizing critical operations, and increasing overall efficiency in small scale chocolate manufacturing.

1. Objective

The objective of this research is to improve the operational efficiency of a chocolate-producing SME by designing and implementing an integrated model based on Lean Manufacturing tools SMED, Poka-Yoke, and Jidoka.

- Reduce changeover time by implementing SMED.
- Reduce operational defects by using a Poka-Yoke visual control system.
- Stabilize the flow between refining and tableting by using a Jidoka system.
- Evaluate the impact of improvements using technical and operational indicators.

2. Literature Review

Flow and variability in chocolate production: Chocolate production processes are highly sensitive to thermal and rheological variations, which directly affect flow stability. Beyond operational efficiency, chocolate production must comply with technical quality requirements associated with cacao-based products. In Peru, the GIP 104 implementation guide for NTP 107.306:2018 + MT 1:2021 establishes practical guidelines to facilitate the application of quality requirements for cacao nibs, reinforcing the importance of stable and controlled processing conditions in the cacao and chocolate value chain (Instituto Nacional de Calidad, 2022). Kumbár et al. (2021) demonstrated that chocolate viscosity depends significantly on temperature, requiring strict control during transfer between stages. Similarly, recent evidence in the food industry indicates that visual control systems improve process visibility, support real time decision making, promote adherence to quality standards, and contribute to continuous improvement in production environments (Mielczarek, 2024). In small-scale plants, this sensitivity is amplified due to manual operations and discontinuous transfers. Flores Pérez et al. (2023) highlighted that inefficient layout design and unnecessary transfers can generate bottlenecks and reduce productivity in SME production systems.

Poka Yoke systems: The use of visual tools and Poka Yoke devices has been widely studied as a mechanism for reducing errors and variability in food processes. Brunelli et al. (2025) explain that visual management uses visual tools such as boards, labels, signs, tables, and digital displays to communicate operational information and alerts to operators, supporting process visibility and more standardized decision-making in production environments. Similarly, Huarcaya Melendez and Platero Mamani (2023) showed that the integration of Lean tools such as 5S and Poka Yoke in the food industry can improve productivity, reduce waste generation, and strengthen process control in operational environments. Poka Yoke, meanwhile, has been effective in preventing human error in manual processes. Trojanowska et al. (2023) showed that Poka Yoke principles, when supported by visual guidance and verification mechanisms, can reduce operator errors and improve task execution in production environments. This makes them relevant for manual-intensive chocolate processes, where filling control and sequence compliance depend strongly on operator decisions.

SMED and reduction of format changeover times: The SMED methodology has been validated as an effective tool for reducing changeover times and increasing operational availability. Barbieri-Silva et al. (2022) proposed a TPM, SMED, and 5S model for a food-sector production line, showing that SMED can support efficiency improvement by reducing setup-related losses and strengthening production availability. García-García et al. (2022) added that standardizing sequences and reorganizing tasks minimizes the variability associated with operator intervention. In the Peruvian context, Mariluz-Cuadros and Minaya-Sanchez (2025) applied Lean tools such as 5S, SMED, and TPM in a food-processing SME, achieving improved equipment availability and a 30.81% reduction in setup times. These contributions support the relevance of SMED in chocolate-making environments where format changes cause significant interruptions.

Lean Manufacturing in Chocolate SMEs: The applications of Lean Manufacturing in chocolate SMEs are still limited but show promising results. Sousa et al. (2023) identified opportunities related to reducing variability, improving flow, and implementing simple controls adapted to the available infrastructure. Matindana and Shoshiwa (2025) highlight that food, and beverage SMEs require Lean implementation approaches adapted to their operational context, available resources, training needs, and technological limitations. For their part, Reyes-Palacios and García-Castro (2024) presented evidence that Lean practices applied in auxiliary operations such as storage can generate significant improvements in consistency and order, demonstrating that low cost tools can be effective even without automation.

3. Methods

3.1 Proposed model and theoretical basis

The model integrates three Lean tools: SMED, Poka-Yoke, and continuous flow with Jidoka. The integration of these tools is consistent with core Lean Manufacturing principles, particularly waste elimination, process standardization, flow continuity, and built-in quality. These principles provide the theoretical foundation of the proposed model and support the reduction of operational variability, interruptions, and defects within the production process. Their selection is based on evidence from the literature demonstrating their effectiveness in food processes and low-automation environments:

- SMED reduces changeover times by separating internal/external activities and standardizing sequences (Moreira & Silva, 2021; García-García et al., 2022; Mariluz-Cuadros & Minaya-Sanchez, 2025).
- Visual Poka-Yoke reduces errors associated with subjective decisions in manual tasks by guiding operators through visual verification mechanisms and reducing execution mistakes (Trojanowska et al., 2023).
- Continuous flow with Jidoka stabilizes chocolate transfer, reducing interruptions and thermal variability (Kumbár et al., 2021; Quevedo Olaya, J.L.,2024)

This study proposes an integrated Lean improvement methodology for defect reduction in a low-automation food-processing SME. The methodology follows an As-Is to theoretical To-Be approach, in which current operational performance is evaluated and contrasted with expected performance levels reported in the literature.

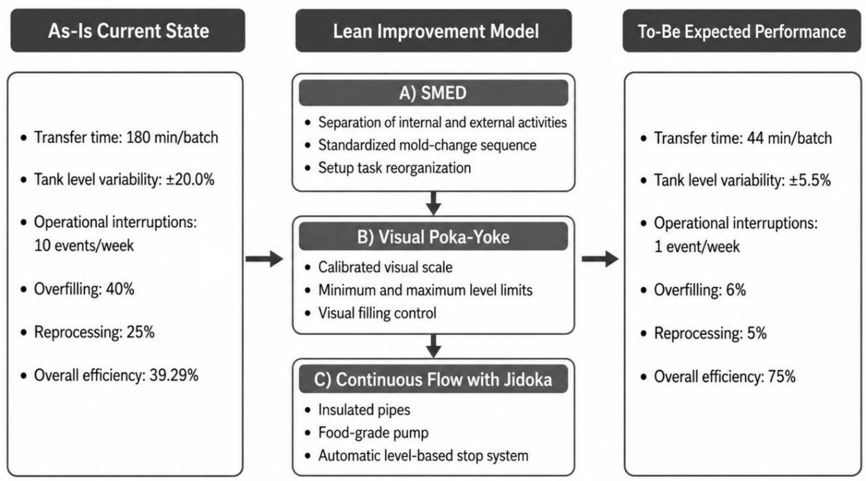


Figure 1. Proposed Lean improvement model based on SMED, Visual Poka Yoke, and Continuous Flow with Jidoka

Figure 1 presents the proposed Lean improvement model structured under an As-Is, intervention, and To-Be expected performance logic. The As-Is condition summarizes the main operational deficiencies identified in the chocolate production process, including excessive transfer time, tank-level variability, operational interruptions, overfilling, reprocessing, and low overall efficiency. The intervention stage integrates three Lean components: SMED for setup standardization, Visual Poka Yoke for filling-level control, and Continuous Flow with Jidoka for stabilized chocolate transfer. The To-Be condition shows the expected performance indicators, expressed with their respective units, ensuring consistency with the validation tables and subsequent results.

3.2 Model validation

The validation combined experimental and simulation methods based on an indicator-oriented validation model. A time motion study was used to characterize the As-Is performance, while a pilot test of the visual Poka-Yoke component was conducted using 16 tank level measurements, which are sufficient to represent short-term operational variability at the process level. Additionally, 30 simulation replications per scenario were performed in Arena to ensure stability and consistency of the performance indicators when comparing the As-Is and To-Be conditions. The simulation model was developed under key assumptions to ensure comparability between both scenarios. These assumptions included stable production demand, normal equipment operation without major mechanical failures, constant processing conditions, operator availability during the evaluated activities, and no significant changes in product formulation or batch size during the simulation period. By controlling these factors, the model focused specifically on evaluating the operational impact of the proposed Lean interventions.

4. Data Collection

Table 1 summarizes the data collection strategy used in the study, detailing the number of samples obtained from each source, the confidence level represented by these sample sizes, and the specific methodology applied. The combination of direct measurement, pilot testing, and simulation provides a statistically reliable basis for characterizing the As-Is system and validating the proposed To-Be model.

Table 1. Data Collection and Confidence Levels

Data Source	Sample Size (n)	Confidence Level Represented	Methodology Employed
Time–motion study (real operations)	75 observations	≈ 95% confidence, since n > 30 ensures stable estimation of mean values in repetitive industrial tasks	Direct measurement of discharge, transfer, and loading times

Poka-Yoke pilot testing	16 measurement s	≈ 90% confidence for early-stage pilot tests with moderate variance	Controlled pilot test to measure tank-level variability and operator accuracy
Discrete-event simulation (Arena)	30 replications per scenario	≈ 95% confidence, considered the standard number of replications for simulation output stability	Simulation modeling of As-Is and To-Be systems to validate flow behavior

5. Results and Discussion
5.1 Proposed Improvements
This section presents the set of improvements proposed and validated in this study, structured according to the operational deficiencies identified in the As-Is scenario. Each improvement addresses a specific root cause changeover variability, manual transfer instability, and overfilling errors and integrates Lean Manufacturing principles, including SMED, Poka-Yoke, and Jidoka. The proposed improvements are supported by numerical evidence from simulations, pilot testing, and comparative performance indicators.
Improvement 1: The SMED methodology was applied to transform operator-dependent mold changes into standardized and repeatable activities by separating internal and external activities, reorganizing tasks, and establishing a fixed setup sequence.
Problem addressed: high variability in changeover times, frequent stoppages, and loss of operational continuity. Numerical impact:

- As-Is interruptions: 10 per week → 1 per week
- Changeover time reduction: 28%, according to simulation and timings
- Greater continuity in the flow to subsequent stages

Improvement 2: Continuous transfer system (Jidoka integration) A continuous transfer system was implemented to replace manual chocolate transfer. The design includes insulated pipes, a food-grade pump, and an automatic level-based stop system.
Problem addressed: 180-minute manual transfer, temperature fluctuations, risk of spills, and WIP accumulation. Numerical impact:

- Transfer time: 180 min → 44 ± 3 min (75% reduction)
- Flow stability: 0 interruptions in 29/30 replicates
- Level variability: ±20% → ±5–6%
- Overall efficiency: 39.29% → 75%

Improvement 3: Visual Poka-Yoke for controlling the buffer tank level, a calibrated visual scale was installed on the buffer tank to eliminate subjective estimation by the operator. A color code was incorporated to indicate the minimum (30%) and maximum (85%) levels.
Problem addressed: Frequent overfilling (40%), imbalance in tempering, and reprocessing. Numerical impact:

- Overfilling: 40% → 6%
- Reprocessing: 25% → 5%
- Level variability: ±20% → ±5–6%

Overall, the proposed improvements demonstrate a significant reduction in operational variability, a substantial increase in process stability, and a measurable improvement in production efficiency. The results confirm that the proposed Lean model is technically feasible, economically accessible, and scalable for chocolate-producing SME seeking to increase capacity without compromising quality.

5.2 Validation
The proposed design was validated using a mixed approach that integrated simulation, pilot plant testing, and statistical analysis. The objective was to verify whether the improvements implemented SMED, continuous flow, and Poka-Yoke generated statistically significant changes with respect to the As-Is process and met the operational

criteria established for the chocolate production system. The data collection procedure, the techniques used, and the validation results are detailed below.

Simulation with Arena (30 replicates per scenario): The As-Is and To-Be scenarios were modeled in Arena, incorporating real transfer times, flow rates, process sequences, and variability observed in the plant. Thirty replicates were run per scenario, allowing stable and comparable distributions to be obtained.

The simulation was used to validate transfer time, flow interruptions, operational stability and overall efficiency Poka-Yoke pilot on site (16 measurements): The actual level of the buffer tank was measured using the new calibrated visual scale. Overfilling, errors, and operator accuracy were recorded under real conditions. This information validated the reduction in reprocessing and level stability.

Operational records and timing (5 weeks) For SMED, weekly interruptions were recorded during the standardization process.
Week 1: 5 interruptions
Week 5: 1 interruption
This confirmed the direct impact of standardizing mold changes.

Operational interruptions:

- H0: λ_As-Is = λ_To-Be
- H1: λ_As-Is > λ_To-Be
- As-Is = 10 interruption/week
- To-Be = 1 interruption/week
- p-value < 0.01

Conclusion: H0 is rejected; SMED significantly reduces interruptions.

Indicator: Interruptions

- Poisson model → p < 0.01
- Significant reduction

Tank level variability

- H0: σ_As-Is = σ_To-Be
- H1: σ_As-Is > σ_To-Be
- As-Is = ±20%
- To-Be = ±5–6%
- p-value < 0.001

Conclusion: H0 rejected; significant decrease in variability.

Indicator: Variabilidad del nivel

- F-test → p < 0.001
- Significantly higher stability

Transfer time:

- H0: μ_As-Is = μ_To-Be
- H1: μ_As-Is > μ_To-Be
- As-Is = 180 min
- To-Be = 44.1 min (IC95%: 43.47–44.73)
- p-value < 0.001

Conclusión: H0 is rejected; transfer time is significantly reduced.

Indicator: Transfer time

- t-test → p < 0.001
- Significant improvement

Overall efficiency:

- H0: η_As-Is = η_To-Be
- H1: η_As-Is < η_To-Be
- As-Is: 39.29%
- To-Be: 75.00%
- Improvement: +35.71

Conclusion: Conclusion: H0 is rejected; the To-Be scenario presents higher overall efficiency than the As-Is scenario.

Indicator: Overall efficiency (%)

- Arena simulation model
- Improvement in overall operational performance

Figure 2. Validation results of operational efficiency and process stability indicators

Figure 2 presents the statistical validation of the main operational indicators evaluated in the As-Is and To-Be scenarios. Unlike a figure focused only on tank-level variability, this validation integrates four key indicators: operational interruptions, tank level variability, transfer time, and overall efficiency. These indicators were selected because they represent the main sources of inefficiency identified in the original process and are directly linked to the objective of improving production efficiency in the chocolate SME. The results show a significant improvement in process stability and operational performance after the implementation of the proposed Lean model. Operational interruptions decreased from 10 to 1 event/week, confirming the effect of SMED on the standardization of changeover-related activities. Tank level variability decreased from ±20.0% to approximately ±5.5%, showing that the Visual Poka-Yoke system improved filling control and reduced dependence on subjective operator judgment. Likewise, transfer time decreased from 180 to 44.1 min/batch, demonstrating the impact of the continuous-flow system with Jidoka on flow stabilization and process continuity. Finally, the overall efficiency increased from 39.29% in the As-Is scenario to 75% in the To-Be scenario. This result is especially relevant because efficiency is the main performance indicator of the study and summarizes the combined effect of the three

Lean components. Therefore, Figure 2 provides methodological and statistical evidence that the proposed model not only improves isolated process variables, but also contributes to a measurable increase in the overall operational efficiency of the chocolate production system.

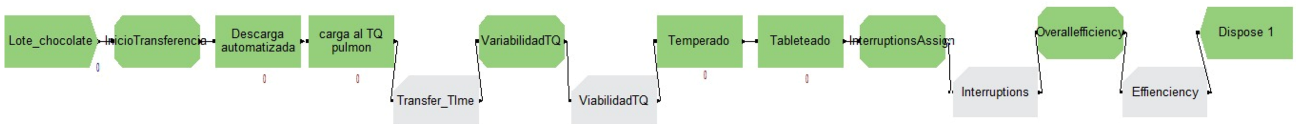


Figure 3. Arena simulation model for To-Be validation with performance indicator records

Figure 3 represents the To-Be simulation model used as the central design validation mechanism. This step is methodologically critical, as it allows the behavior of the proposed system to be tested in a controlled environment prior to its physical implementation, reducing risks and ensuring the robustness of the engineering design. The model includes specific Record modules for the main performance indicators evaluated in the study: transfer time, tank level variability, operational interruptions, overfilling, reprocessing, and overall efficiency. The simulation was executed using 30 independent replications for both the As-Is and To-Be scenarios. The outputs generated by the Record modules were exported to Arena Output Analyzer in order to compare the confidence intervals of the main validation indicators. This comparison allowed the evaluation of whether the confidence intervals of both scenarios overlapped. The results showed that the To-Be scenario presented consistently better performance than the As-Is scenario, with no relevant overlap between the confidence intervals of the main indicators. Therefore, the Output Analyzer validation supports that the improvements obtained were not isolated simulation results, but consistent differences between the current and improved scenarios.

From an analytical perspective, the simulation demonstrates that the integration of SMED, Visual Poka-Yoke, and continuous flow with Jidoka operates as a coherent system under realistic production conditions. Consequently, the simulation not only validates the technical feasibility of the model, but also supports its capacity to achieve sustained improvements in flow stability, operational continuity, and overall efficiency.

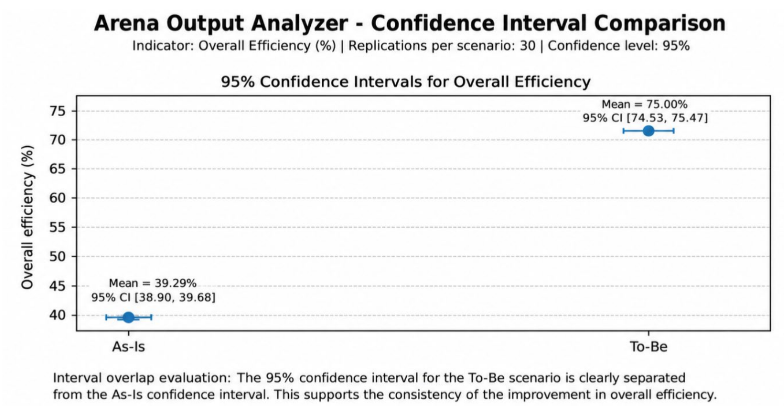
5.3 Analysis

This section presents the figures generated from the data obtained in the simulation and the pilot study. Each figure includes its respective interpretation and conclusions (Table 2).

Table 2. Indicators

Indicators	As-Is	To-Be
Transfer Time (min)	180	44
Variability (%)	20 %	5.5 %
Interruptions	10	1
Overfilling (%)	40%	6%
Reprocessing overall	25%	5%
Overall Efficiency (%)	39.29%	75%

The numerical results obtained show substantial improvements in all indicators evaluated after the implementation of the improvement model. Transfer time, one of the main bottlenecks in the As-Is process, was drastically reduced from 180 min to 44 min in the To-Be scenario, demonstrating the efficiency of continuous flow through pumping. Likewise, the variability of the buffer tank level decreased from 20% to 5.5%, achieving stable performance within the limits accepted by GMP. Operational interruptions, initially recorded at 10 events, were reduced to 1, reflecting greater production continuity. In terms of process quality and stability, the frequency of overfilling went from 40% to 6%, while total reprocessing decreased from 25% to 5%, confirming the effectiveness of Poka-Yoke visual control. Finally, the overall efficiency of the process showed a significant increase, going from 39.29% in the As-Is state to 75% in the To-Be design, validating the comprehensive impact of the proposed Lean model on the productivity and operational performance of the chocolate plant.



Scenario	Tally / Indicator	N	Mean (%)	Std. Dev.	Half-Width	95% CI	CI Overlap
As-Is	Overall_Efficiency	30	39.29	1.035	0.386	[38.90, 39.68]	No overlap
To-Be	Overall_Efficiency	30	75.00	1.257	0.469	[74.53, 75.47]	No overlap

Figure 4. Output Analyzer confidence interval comparison for overall efficiency

Figure 4 shows the confidence interval comparison for overall efficiency using Arena Output Analyzer. The As-Is scenario obtained a mean efficiency of 39.29% with a 95% confidence interval of [38.90%, 39.68%], while the To-Be scenario obtained 75.00% with a 95% confidence interval of [74.53%, 75.47%]. Since both intervals do not overlap, the improvement in overall efficiency is statistically consistent and validates the performance of the proposed Lean model.

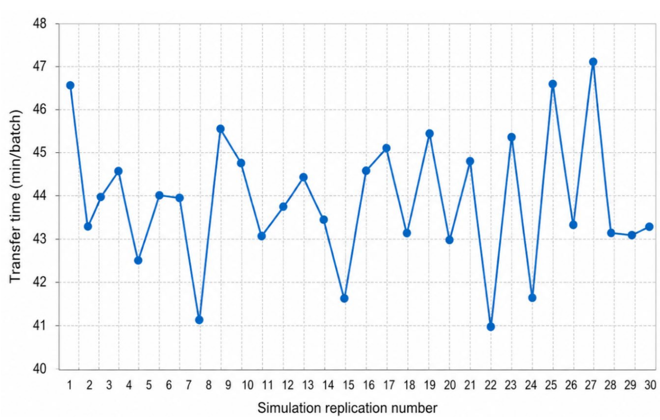


Figure 5. Transfer Time by simulation replication for the To-Be scenario

Figure 5 presents the transfer time results obtained from 30 simulation replications of the To-Be scenario. The X-axis represents the simulation replication number, while the Y-axis represents the transfer time expressed in minutes per batch. The data show a stable distribution of transfer times ranging between approximately 41 and 47 min/batch, with an average close to 44 min/batch. This performance reflects a substantial improvement compared with the As-Is condition, in which manual transfer required 180 min/batch. Overall, the automated pumping system reduces total transfer time by nearly 75% and supports a more continuous and stable flow toward downstream stages.

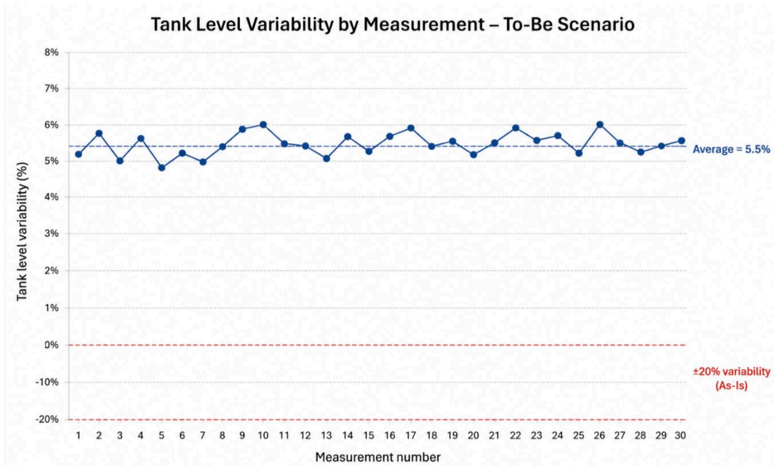


Figure 6. Tank Level Variability by measurement – To-Be scenario

Figure 6 displays the tank level variability recorded across 30 measurements of the To-Be scenario. The results reveal a consistently stable behavior, with values ranging between 5 % and 6 %, far below the ±20 % variability observed in the As-Is condition. This narrow range demonstrates the effectiveness of the implemented visual Poka-Yoke system in ensuring precise and repeatable filling levels, independent of operator judgment. The absence of abrupt fluctuations or deviations indicates strong process stability, fulfilling BPM and HACCP requirements for controlled liquid-level operations in food processing. Moreover, the uniformity of the results validates that the redesigned system operates under statistical control, minimizing the risks of overfilling, reducing reprocessing, and improving synchronization with downstream operations in the tempering and molding stages.

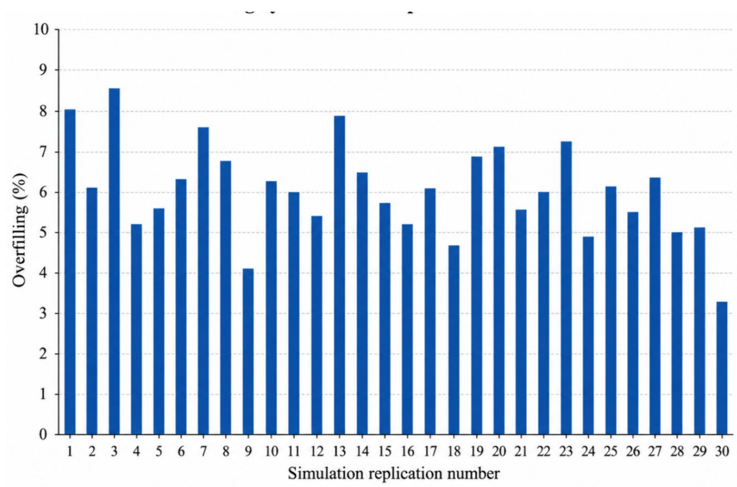


Figure 7. Results of overfilling (%) and Photograph of the lung tank with the control scale.

Figure 7 presents the overfilling results obtained from 30 replicates of the To-Be scenario, together with a photographic record of the buffer tank equipped with the visual Poka-Yoke control system. The bar chart shows that all measurements remain consistently within a narrow range between 3.3% and 8.6%, yielding an average value of 6.07%. This improved distribution represents a substantial reduction compared to the As-Is condition, where deviations routinely exceeded 20% due to the operator's subjective estimation and the lack of standardized visual limits. The steady pattern observed across the 30 data points confirms that the implemented Poka-Yoke enables reliable and repeatable level control, minimizes the likelihood of overfilling, and contributes directly to reducing reprocessing and stabilizing downstream operations. The accompanying photograph provides visual evidence of the installed device, highlighting the integration of the calibrated measurement scale with the holding tank. In alignment with BPM and HACCP requirements, maintaining tank levels within controlled limits constitutes a critical indicator of operational safety and product quality throughout the chocolate production process.

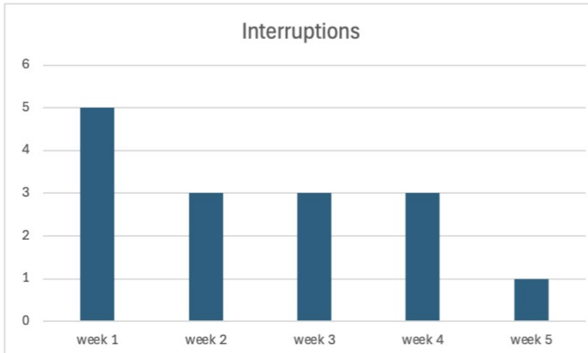


Figure 8. Weekly Reduction of Operational Interruptions after SMED Implementation

Figure 8 presents the weekly interruptions recorded during the validation of the SMED implementation. In Week 1, five interruptions were observed, reflecting the persistent coordination issues and the absence of a standardized setup sequence typical of the As-Is system, which historically accumulated up to 10 interruptions per week. After the application of SMED specifically through the separation of internal and external activities, task reorganization, and the establishment of a repeatable setup procedure the number of interruptions decreased noticeably. Weeks 2, 3, and 4 stabilized at three interruptions each, showing improved workflow continuity and reduced operational stops. By Week 5, the system reached only one interruption, marking a reduction of nearly 90% compared to the original As-Is condition. Moreover, the progressive reduction observed throughout the five weeks period suggests that the benefits of SMED extend beyond the immediate reduction of setup times. As operators became familiar with the standardized procedures, process execution became more predictable and less dependent on individual experience. This trend indicates that the improvement is sustainable over time and supports the long-term operational stability of the production system.

5.4 Comparative Discussion with Previous Studies

The results obtained are consistent with previous studies on Lean Manufacturing and process improvement. García-García et al. (2022) showed that SMED helps reduce changeover time in food factories through task standardization and the separation of internal and external activities. This supports the reduction of interruptions achieved in this study. García-Alcaraz et al. (2021) emphasized that Lean tools related to material flow, such as SMED and continuous flow, improve operational performance by reducing non-value-added activities. This is aligned with the transfer time reduction from 180 to 44 min/batch obtained in the To-Be scenario. Regarding error prevention, Hakim and Hellyward (2021) demonstrated that Poka Yoke mechanisms are useful for reducing human error in manual manufacturing operations. This supports the use of the visual scale in the buffer tank, which helped reduce overfilling and reprocessing. In the chocolate sector, Quevedo Olaya (2024) highlighted that Lean Manufacturing can reduce time waste and improve operational control in chocolate production processes. Similarly, this study confirms that Lean tools can be adapted to artisanal chocolate SMEs with limited automation. Finally, Kumbár et al. (2021) showed that chocolate mass behavior is affected by temperature and flow conditions. Therefore, stabilizing the transfer process is relevant not only for productivity, but also for maintaining process stability in chocolate manufacturing.

Limitations: Despite the positive results obtained, this study presents certain limitations. First, the proposed model was developed and validated within a single chocolate-producing SME, which may limit the generalizability of the findings to other production environments. Second, although the validation combined pilot testing and discrete-event simulation, the complete implementation of all proposed improvements was not evaluated over an extended operational period. Finally, the model was specifically designed for low automation production systems and may require adaptation before being applied to highly automated manufacturing facilities.

Discussion: The results obtained demonstrate that the improvements implemented are effective; however, the study reveals that chocolate producing MSMEs still have ample room for further technological development. Future research could explore inexpensive IoT sensor solutions for monitoring critical variables in real time, as well as hybrid automation systems that support repetitive tasks without compromising the artisanal character of the product. It would also be valuable to evaluate advanced planning tools adapted to micro-industries and conduct comparative studies between MSMEs to identify common gaps in the sector. These lines of research would make it possible to consolidate a more comprehensive model of modernization and sustainability for small chocolate companies.

6. Conclusion

This study achieved its objectives by validating an integrated Lean model composed of SMED, visual Poka-Yoke, and continuous flow with Jidoka, each addressing a specific operational limitation of the As-Is system.

First, the SMED component fulfilled the objective of reducing changeover time by reorganizing internal and external activities and standardizing the setup sequence. This intervention led to a measurable reduction in interruptions and confirmed the feasibility of applying SMED in low-automation chocolate SMEs.

Second, the Poka-Yoke visual control met the objective of reducing defects associated with tank-level variability. Pilot testing demonstrated a clear decrease in overfilling frequency and variability, validating the effectiveness of a low-cost visual device for error prevention in manual operations.

Third, the continuous flow with Jidoka accomplished the objective of stabilizing the transfer between refining and tempering. Simulation results showed substantial reductions in transfer time, flow interruptions, and variability, confirming that the proposed system enhances process stability and supports continuous operation.

From a scientific perspective, the main contribution of this work lies in demonstrating that Lean tools traditionally applied in large industries can be successfully adapted to chocolate-producing MSMEs, even under conditions of limited resources. This fills a gap in the literature, which until now has shown evidence mainly in larger-scale plants. Likewise, the methodological combination of computer simulation and pilot validation constitutes a relevant technical contribution, integrating quantitative rigor and empirical verification to ensure the viability of the design before its actual implementation.

Finally, the results show that the proposed improvements not only increase process efficiency (up to 75%), but also reduce rework, stabilize critical operations, and strengthen the reliability of the production system, contributing to the operational sustainability of companies in the Peruvian chocolate sector

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