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Improvement Model for the Production Area to increase Labor Productivity through Lean Manufacturing tools in a bakery company

Ana Paula Fouscas-Chang, Bsc[1]; Juan Adrian Lucero-Ugaz, Bsc[2]; Jorge Antonio Corzo-Chavez, Msc[3]; Gino Viacava-Campos, Msc[4]
Carrera de Ingeniería Industrial, Universidad de Lima, Perú, 20200821@aloe.ulima.edu.pe[1], 20201215@aloe.ulima.edu.pe[2], jacorzo@ulima.edu.pe[3], geviacav@ulima.edu.pe[4]

Abstract*– The global bakery industry faces persistent productivity challenges due to its high dependence on manual operations and limited technological adoption, creating substantial opportunities for process optimization. The company under study, dedicated to the production of healthy cookies made from Peruvian grains, exhibits a labor productivity of 1.46 kg/man-hour—less than half of the sector benchmark of 3 kg/man-hour—resulting in an annual economic impact of approximately 146817 USD. Key contributors to this gap include excessive setup time, prolonged cycle time, and a high defective rate. This research proposes an integrated process improvement model designed to enhance productivity in low-automation bakery environments. The model combines Lean Manufacturing tools, including 5S for workplace organization, SMED for setup time reduction, and process standardization through Standard Operating Procedures (SOPs) and Good Manufacturing Practices (GMP). The proposed model was evaluated through discrete-event simulation, allowing the validation of its impact prior to implementation. The results show significant improvements, including a 105% increase in labor productivity, a 46% reduction in cycle time, a 49% reduction in setup time, and an 86% decrease in defective products. This study contributes by providing a practical and replicable integrated Lean-based model tailored to SME bakery environments, demonstrating that the combined application of multiple tools generates measurable productivity improvements in a context that has been less explored in existing research.

***Keywords:* Bakery industry, Labor Productivity, Lean Manufacturing, 5S, SMED, Process standardization.**

I. Introduction

A. Background

The bakery industry in Peru is a productive sector with a high impact and significant social relevance. This sector supplies essential consumer goods such as bread, cookies, and other pastries. Furthermore, it is primarily composed of micro and small businesses, many of which operate using artisanal or semi-industrial processes [1]. Despite this, consumption remains consistently high: sales reached US$253 million in 2020, of which 62% corresponded to cookies only [2]. In 2023, per capita cookie consumption in Peru was 1.7 kilograms, while in 2024 the market value reached US$163.4 million, confirming sustained growth during the 2020-2024 period [3]. This expansion is driven by consumer preferences for healthier, organic, and gluten-free alternatives [4], expanding business opportunities and projecting high revenue potential in the coming years and creating a favorable environment for efficiency-oriented engineering interventions.

The company under study participates in this dynamic market by producing healthy cookies made with native Peruvian grains. However, its operations are characterized by disorganized work areas, extended setup times, and non-standardized tasks. As a result, it exhibits critical performance deficiencies, reflected in a low level of productivity compared to the industry standard.

This research project aims to demonstrate that implementing an integrated model using Lean Manufacturing tools improves labor productivity in the company. Specific objectives include analyzing the labor productivity gap in Peru's bakery industry, diagnosing operational inefficiencies within the company, proposing an engineering-based Lean improvement model validated through simulation, and assessing its economic viability.

To evaluate the performance of the proposed model, a set of key performance indicators (KPIs) was defined. These include labor productivity (kg/man-hour), setup time (minutes), cycle time (minutes per batch), and defect rate (% of non-conforming units). These KPIs enable the quantitative evaluation of the intervention's effectiveness and its contribution to improving operational stability, product quality, and economic performance.

B. Literature Review

The core of this study relies on a Systematic Literature Review (SLR), which aims to map out significant research concerning diagnostic tools and operational shortcomings within the manufacturing sector. The adopted approach prioritized authoritative references that directly correspond to the diagnostic metrics analyzed: production bottlenecks, setup duration, and quality control stability.

A systematic search within prominent academic databases—including Scopus, ScienceDirect, and Web of Science—served as the starting point for the selection procedure. To ensure relevance, priority was given to articles from high-impact journals published within the last five years (2020–2025). The initial search utilized keywords including "Bottleneck Analysis", "Setup Time Reduction", "Work Measurement", "Visual Inspection Reliability", and "Defect Propagation", which were generating a starting corpus of records. This list was then streamlined using the PRISMA guidelines, leading to a curated set of articles that formed the basis for the diagnostic models.

The literature identifies bottlenecks as the primary constraint on system performance, emphasizing that they restrict the total throughput of any production line [5]. Recent systematic reviews highlight that diagnosing these constraints is the initial step required to dimension their impact on queues, waiting times, and downstream resource utilization [6]. Closely related to flow constraints, extended preparation times significantly reduce the effective availability of bottleneck resources. Empirical evidence suggests that prolonged setup times minimize flexibility and increase operational costs, whereas reducing them is critical to increasing capacity and responsiveness in batch production environments [7].

Regarding operational efficiency, the literature underscores the importance of work measurement techniques for quantifying non-productive times such as searches, movements, and micro-stops. Work sampling is highlighted as a robust method to estimate the percentage of shift time dedicated to specific activities [8], while time studies determine the standard duration required at a normal pace, allowing for the separation of natural variation from avoidable delays [9]. These methodologies are essential for establishing a baseline for labor productivity.

Quality control processes present another significant challenge in manual operations. Traditional visual inspection methods are often cited as subjective and inconsistent due to inherent human variability [10]. Furthermore, operator fatigue has been proven to significantly decrease detection accuracy over time, leading to variability in quality assurance [11]. The late detection of these defects propagates waste throughout the value chain, consuming capacity and materials, which ultimately increases unit costs and generates direct economic losses [12].

Finally, the absence of continuous monitoring systems prevents the timely detection of deviations. Evidence indicates that the lack of real-time monitoring hinders the identification of inefficiencies in resource use [13]. Conversely, data-driven approaches in manufacturing have been shown to reduce non-productive times—such as setup times—by more than 30% and improve process flow [14]. Collectively, these literary findings validate the multidimensional nature of the productivity problem and support the need for an integrated diagnostic approach—combining flow, time, and quality analysis—to design a robust Lean improvement model.

II. Problem

By conducting in-situ assessments and time studies during the 2024 period, the diagnosis revealed that the critical challenge facing the organization is the low level of labor productivity in the cookie production. This operational challenge directly undermines the firm's financial performance, generating an annual economic loss estimated at USD 146,817 due to operational inefficiencies. It is important to mention that operators perform critical tasks such as dosing and packaging manually without standardized procedures, leading to high variability in execution times and frequent errors; similarly, the absence of workplace organization (5S) causes excessive motion and search times for tools and supplies.

The analysis of the production flow revealed that the mixing process acts as the system's primary bottleneck. Data collection showed that the cycle time currently stands at 21.89 minutes per batch. This duration significantly exceeds the standard processing time of 15 minutes reporting in the sector [15], causing idle time in downstream operations such as baking and cooling, and limiting the total throughput of the line.

Furthermore, based on the analysis of non-productive times, it is typical to experience prolonged machine downtimes during format changeovers (changing from circular to rectangular cookies). It was documented that the setup time averages 1.37 hours per day (82 minutes), consuming a significant portion of the available shift time. This inefficiency occurs because all preparation activities are performed while the machine is stopped (internal setup), contrasting sharply with the Lean standard of ≤ 30 minutes achieved through SMED methodologies and the standard of 45 minutes [16], [17].

In addition, the quality indicator is crucial for assessing the efficiency of resource utilization. The defective rate calculation is based on the number of non-conforming units rejected due to weight deviations, sealing failures, or aesthetic defects. The indicator currently stands at 8.45%, which is alarmingly high compared to the industry acceptance limit of 3% [14]. This waste is largely attributed to the lack of standardized controls during the manual dosing and visual inspection stages.

To assess the operational gap, it is crucial to examine the sector's key performance indicators (KPIs), derived from a review of the literature and successful industry applications. Fig.1 summarizes the dependent variable (labor productivity) and the independent variables previously explained, comparing the values of the company under study against the sector gaps. As observed, the current productivity of 1.46 kg/man-hour reveals a gap of 1.54 kg/man-hour against the reference of the minimum of 3.0 kg/man-hour [18].

Indicators	Bakery Industry (sector)	Company under study	Percentage difference
Labor Productivity	3 kg/man-hour	1.46 kg/man-hour	48.66%
Cycle Time	15 minutes	21.89 minutes	-68.52%
Setup Time	30 minutes	82 minutes	-36.58%
Defective Rate	3%	8.45%	-5.45%

Fig. 1 Comparative Analysis between Sector and Company under study

Root causes were systematically identified using a problem tree to determine the factors linked to the low labor productivity in the baking process. As illustrated in Fig. 2, the analysis highlights three main drivers: high cycle times due to non-standardized manual operations, elevated setup times caused by a lack of defined changeover procedures and a high defect rate stemming from manual dosing and packing errors. Consequently, the research goals focused on utilizing Lean tools like 5S, SMED, and Standardization (SOPs/GMP) to mitigate these inefficiencies and close the productivity gap.

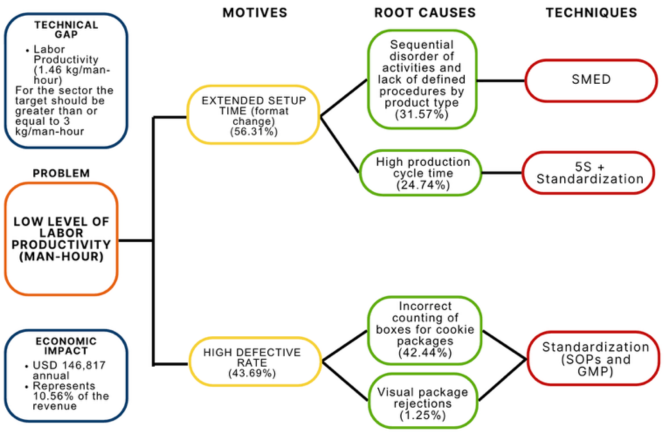


Fig. 2 Problem Tree

III. Methodology

The root causes identified in the diagnosis were directly associated with three specific engineering tools selected from the literature review. The 5S methodology was applied to address the disorganized work environment and excessive motion observed in the mixing and dosing areas. The proposed improvement for this tool focuses on stabilizing the physical environment through sorting and organizing, thereby reducing non-productive search times and creating a foundation for further optimization.

The SMED (Single-Minute Exchange of Die) technique was employed to tackle the critical issue of prolonged setup times, which severely limited the bottleneck's capacity. This tool facilitated the separation of internal and external setup activities, the conversion of internal tasks to external ones, and the streamlining of operations to maximize machine uptime during format changeovers.

Regarding the high variability in manual tasks, Standardization was implemented through visual Standard Operating Procedures (SOPs) and Good Manufacturing Practices (GMP) checklists. These measures were applied specifically to the dosing, quality control, and packaging stations to reduce the defect rate. For the validation of these improvements, a simulation model was developed using Arena software. To ensure data reliability, a sample size calculation was performed based on a preliminary sample of 50 production orders. Applying a 95% confidence level ($Z = 1.96$), the required sample size was determined to be 19 observations per critical activity, which served as the input for the model's stochastic distributions.

Integrating these methodologies, a comprehensive improvement model was designed to transform the production system from its current state to an optimized one. The proposed model is illustrated in Fig. 3.

Fig. 3 Implementation method of the proposal general model

A. *Component 1: Improvement of the physical environment and initial organization - 5S*

To stabilize the work environment as a prerequisite for advanced process improvements, the 5S methodology was implemented, beginning with a comprehensive diagnostic audit. The initial assessment evaluated compliance in the five pillars: Seiri, Seiton, Seiso, Seiketsu, and Shitsuke. The results revealed a critical lack of organization, with the following compliance scores: 40% in Sort (Seiri), 40% in Set in order (Seiton), a critical 25% in Shine (Seiso), 40% in Standardize (Seiketsu), and 25% in Sustain (Shitsuke), which classified the condition of the area as “Deficient”.

In the Sorting phase (Seiri) of the 5S methodology, a Red Tag system was developed to identify, document, and track unnecessary items located in the area. This system includes essential fields such as item name, category, location, quantity, estimated value, reason for classification (obsolete, defective, contaminating, among others), and proposed disposal method (disposal, sale, relocation, return to supplier, etc.). It also includes spaces for evaluation and signature by those responsible, ensuring traceability and control in the final disposal of the identified material. The systematic use of this card facilitates the cleaning of the work area, reduces the accumulation of unnecessary materials, and directly contributes to the reduction of unproductive time and operational risks. The effectiveness of the implementation was monitored through sequential assessments.

As shown in Fig. 4, the radar chart illustrates the evolution of 5S compliance from the initial baseline (Audit 1) to the consolidated state (Audit 3). The results indicate a significant improvement, achieving scores above 80% in the first three pillars, thereby confirming the stabilization of the work environment required for further Lean interventions.

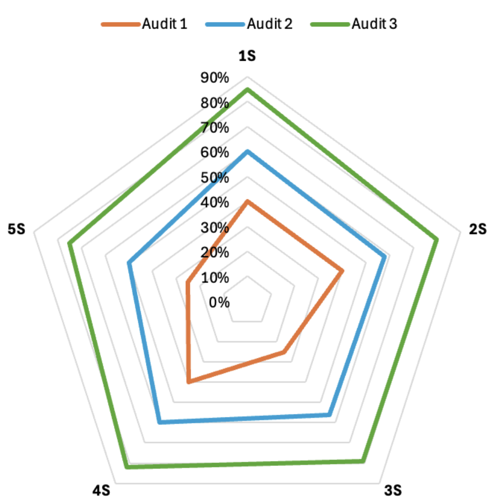


Fig. 4 5S Audit Scorecard

B. *Effective reduction of format changeover (setup) times – SMED*

To address the critical setup time of 82 minutes, the SMED methodology was applied to the 28 identified changeover activities through a continuous three-stage intervention designed to maximize machine availability. The process begins with the separation of internal and external elements, where an initial diagnosis revealed that 74% of activities were performed while the machine was stopped. In this phase, preparation tasks such as the verification of production orders, the retrieval of cleaning kits, and the preliminary weighing of ingredients were reclassified as external, moving them to the pre-setup stage while the equipment remained in operation.

Subsequently, the intervention focused on the conversion and streamlining of internal tasks, optimizing the remaining operations through specific technical and organizational changes. Key improvements implemented in this phase included the parallel assignment of two operators for cleaning duties to drastically reduce downtime, the introduction of fast-rinse detergents to speed up sanitization, and the installation of fixed mechanical stops on rollers and cutters. These engineering adjustments eliminated the need for manual calibration and repeated mechanical adjustments, significantly smoothing the transition between formats.

The final phase aimed at "Zero Prep" and standardization, seeking to eliminate adjustments entirely. This was achieved by implementing digital parameter templates for the mixer and oven, allowing for instant configuration without trial-and-error. Additionally, packaging materials were pre-staged in dedicated racks to ensure immediate availability. These combined actions eliminated the need for trial runs, establishing the first batch of the new format as a standard product. As summarized in Fig. 5, this systematic approach reduced the total setup time from 82 minutes to 42 minutes, representing a 48.8% reduction in non-productive time.

N°	Activity	AS IS		TO BE	
		Initial classification	Time (minutes)	Final classification	Time (minutes)
1	Verify production order	External	3	External	1
2	Transfer and prepare main ingredients	External	3	External	1
3	Transfer special ingredients for the new flavor	External	3	External	2
4	Remove leftover dough	Internal	3	Internal	2
5	Wash or disinfect paddles and hoppers	Internal	3	Internal	2
6	Check and clean sieves and containers	Internal	3	External	1
7	Weigh ingredients for the new formula	External	4	External	2
8	Adjust dispensers	Internal	3	Internal	2
9	Load ingredients into mixer	Internal	3	Internal	2
10	Set mixing parameters	Internal	2	Internal	1
11	Remove crumbs from rollers	Internal	3	Internal	2
12	Install new molds	Internal	4	Internal	2
13	Adjust dough thickness	Internal	2	Internal	1
14	Clean trays and oven residue	Internal	3	Internal	2
15	Preheat oven	External	4	External	2
16	Adjust fans/cooking time	Internal	3	Internal	1
17	Prepare cooling area	External	2	External	1
18	Clean conveyor belt	Internal	3	Internal	2
19	Place coil or packaging material	Internal	4	External	2
20	Configure packaging machine	Internal	3	Internal	1
21	Adjust cutting blades	Internal	3	Internal	1
22	Check and place labels	External	2	External	1
23	Configure target weight	Internal	2	Internal	1
24	Configure manual packaging per box	Internal	3	Internal	1
25	Check expiration date printer	Internal	2	External	1
26	Final line cleaning	Internal	3	Internal	2
27	Produce test batch	Internal	3	Internal	2
28	Verify initial quality control	Internal	3	External	1
TOTAL (minutes)		-	82	-	42

Fig. 5 Reclassification of activities and Redistribution of setup times according to SMED Procedure phases

C. *Clear definitions of manual operations – Standardization (SOPs and GMP)*

The third component addressed the high defect rate of 8.45%, caused mainly by human variability in manual tasks such as dosing, visual inspection, and packaging. To mitigate this, the standardization strategy focused on the design and implementation of visual standard operating procedures (SOPs) and good manufacturing practice (GMP) checklists. Unlike traditional text-heavy manuals, these visual SOPs use figures and color-coded instructions to ensure immediate understanding and consistent execution by operators, regardless of their level of experience. Specific visual guides were developed for critical control points. For the dosing stage, the SOP established strict tolerance limits (2%) for ingredient weighing; for baking, it defined precise temperature and time parameters; and for packaging, it standardized the arrangement of units per box to eliminate counting errors. As illustrated in Fig. 6, these preliminary visual SOPs provide step-by-step instructions for key activities, serving as ongoing training tools in the workplace.

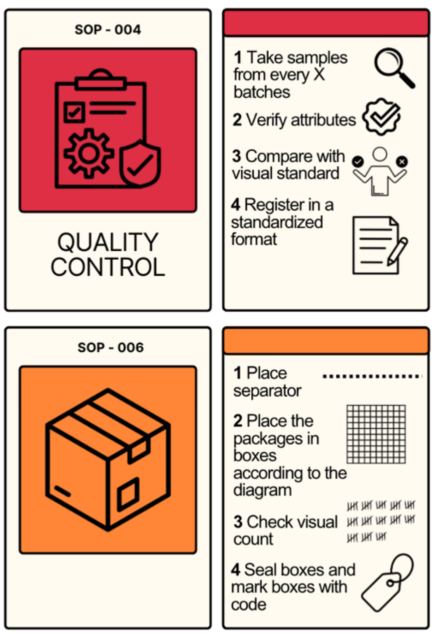


Fig. 6 Visual SOP´s

Furthermore, to reinforce operational discipline and hygiene standards, a specific GMP Checklist was designed. As shown in Fig. 7, this tool mandates the verification of critical control points—such as equipment calibration, absence of foreign matter, and package sealing integrity—prior to the release of each batch, shifting the focus from defect detection to defect prevention.

GMP CHECKLIST		
Activity Description	**Approved step**	**Additional comments**
Are the surfaces in the packaging area **clean** and **disinfected** according to protocol (no visible residue, signed checklist)?	☐	
Has the filling machine **been calibrated** and does it have a record of the adjustment (±2 g tolerance on the scale)?	☐	
Is the **weight of the finished product** within the standard range (30 g ± 2 g)?	☐	
Is the **absence of foreign materials** (plastic, metal, glass, etc.) in the area and product confirmed?	☐	
Is the **packaging seal uniform,** with no visible holes or openings?	☐	
Is the label legible, securely attached, and does it contain complete information (**batch number, production/expiration**	☐	
Are the **boxes aligned, sealed**, and contain the **correct number** of units?	☐	
Was the **batch traceability** recorded (time, production line, responsible operator)?	☐	

Fig. 7 GMP Checklist for Quality Control

To ensure the effective adoption of these standards, a systematic deployment workflow was structured as shown in Fig. 8. This process follows a five-stage cycle starting with the diagnosis of critical variables and the design of guidelines by the Work Team. Before implementation, a validation gate requires Plant Manager authorization to ensure alignment with strategic goals. Subsequently, the workflow emphasizes operator training to bridge the gap between documentation and practice, culminating in a continuous improvement loop sustained by regular audits to prevent process degradation.

The workflow further illustrates how the deployment progresses from the initial assessment to the structured development of standardized procedures. After identifying the critical tasks and sources of variability, the Work Team drafts the SOPs, detailing operational steps, responsibilities, and quality requirements needed to ensure process consistency. These drafts then move through two decision gateways—authorization and approval—that function as quality checkpoints, confirming that the proposed procedures are technically sound, feasible for operators, and aligned with GMP and organizational policies.

Following approval, the process transitions to the training stage, which is essential for ensuring that operators internalize the new standards. Training sessions combine theoretical explanation with practical demonstrations, allowing operators to understand the rationale behind each step and the critical control parameters that must be respected. This structured approach helps bridge the gap between documented procedures and real operational execution, facilitating a smooth and reliable implementation on the production floor.

Finally, the workflow incorporates a continuous improvement mechanism through ongoing audits that assess adherence to the standardized methods and identify deviations or improvement opportunities. As part of this cycle, the model also accounts for reprocessing activities, which address units with packaging defects such as blurred prints, misaligned labels, incomplete seals, or unreadable information. By explicitly modeling this flow, the organization gains visibility into the operational impact of rework and reinforces standardization practices that aim to reduce its occurrence. This integrated approach ensures long-term sustainability, process discipline, and consistent product quality.

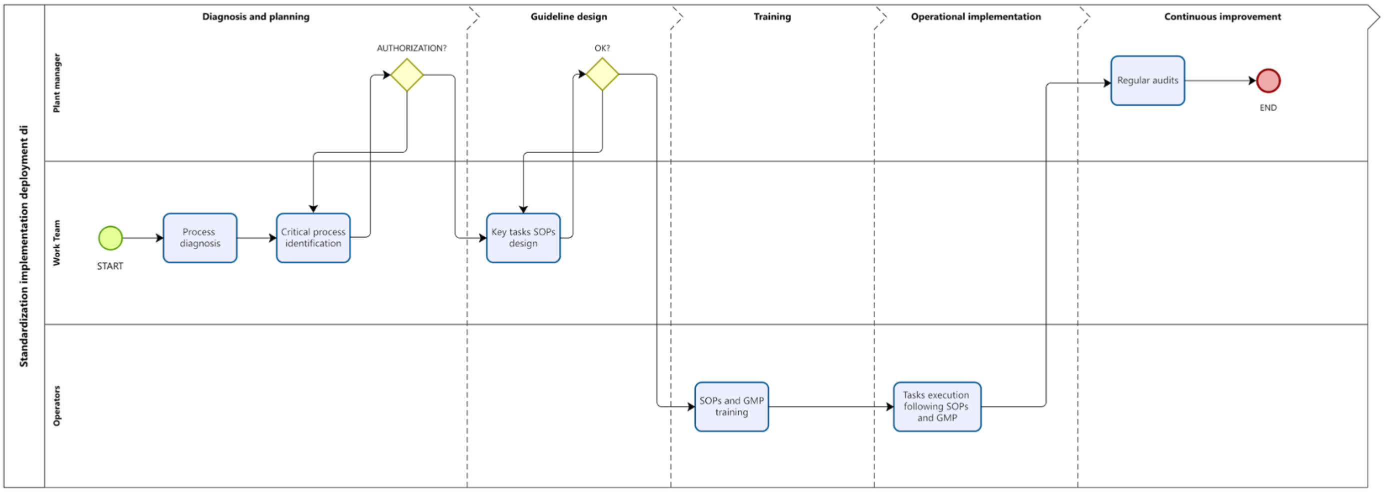


Fig. 8 Standardization Implementation Deployment Diagram

To quantitatively evaluate the impact of the integrated Lean tools while avoiding disruptions to real operations, a discrete-event simulation model was developed in Arena. The To-Be model, presented in Fig. 9, replicates the entire production flow—from entity arrivals through mixing, baking, cooling, sealing, packaging, and warehousing—using the optimized operational parameters derived from the improvement phase.

The simulation logic incorporates the reduced setup time of 42 minutes obtained through SMED and the recalibrated rejection probability of 1.2% at the Quality Control decision node, achieved through standardization and improved work methods. The model was executed with five replications to ensure statistical consistency and minimize variability across runs.

The simulation results indicate a projected labor productivity of 2.99 kg/man-hour, corresponding to a 104.8% improvement compared to the baseline. These findings validate that the combined application of 5S, SMED, and Standardization effectively reduces the identified technical gaps and aligns the system's performance with industry benchmarks.

Additionally, the To-Be model incorporated the reprocessing activity, which represents the specific flow of cookies whose packaging has defects such as blurred printing, misaligned labels, incomplete sealing, or illegible information. In the simulation logic, these units are automatically diverted to a sub-process where they are inspected, removed from the defective packaging, and refunded or reconditioned according to defined standards. This reprocessing block also considers the additional time required for relabeling, reinspection, and extra packaging material consumption, allowing for quantification of its real impact on system efficiency. The inclusion of this flow in Arena not only improves the fidelity of the model with respect to actual operation but also allows us to evaluate how the reduction of printing and sealing errors—achieved through standardization and visual control—decreases the rework load and indirectly contributes to the increase in productivity reflected in the simulation results.

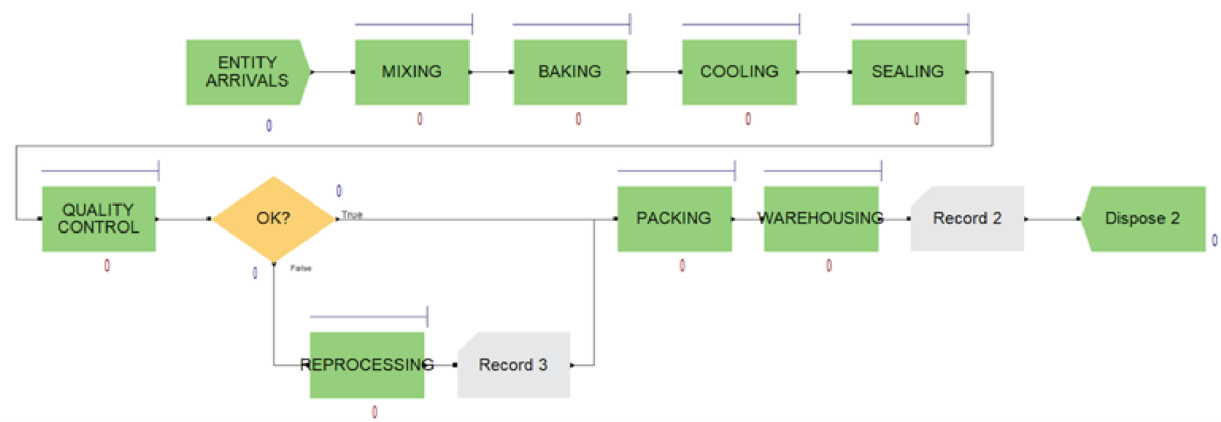


Fig. 9 Arena Model

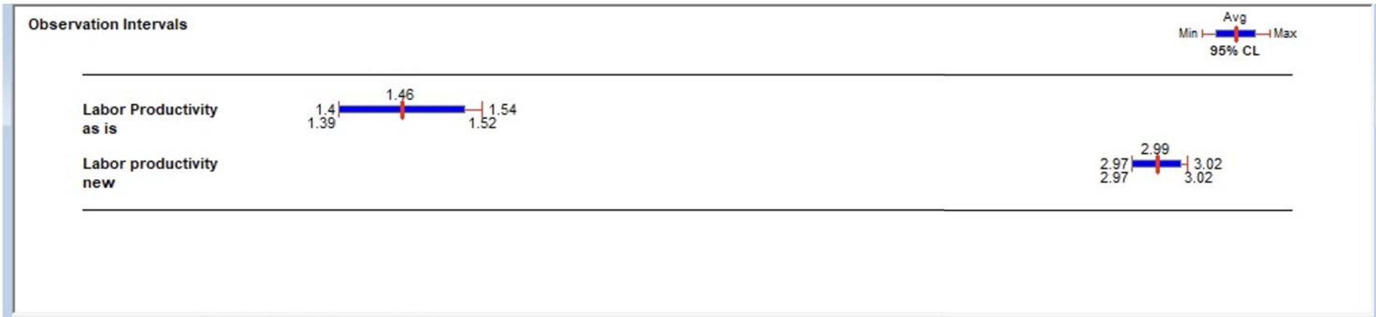
IV. Results

A. Output Analyzer Results

After modeling the AS IS and TO BE scenarios, the results were analyzed by comparing them using the Output Analyzer in the Arena simulator, considering a confidence level of 95% and 5 replicates.

The simulation of Productivity per Man-Hour, calculated as total production in kilograms divided by man-hours worked, validates the effectiveness of the Lean improvement proposal.

The baseline scenario, or "As-Is" (current situation), yielded an average productivity of 1.46 kg/h-h, a value that confirms the initial diagnosis. By applying the "To-Be" model—which integrates SMED (setup reduction) and Standardization (error reduction) improvements—the projected average productivity increases significantly to 2.99. This improvement, presented in Fig. 10, demonstrates that the engineering proposal is robust and achieves the fundamental objective of the project: to bring the company's performance closer to the industry standard of 3.0 kg/h-h. Therefore, the simulation validates that the implementation of Lean tools will have a direct impact on human resource efficiency, doubling their performance.



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Labor Productivity a s is	1.46	0.0504	0.0625	1.4	1.54	5
Labor productivity n ew	2.99	0.0197	0.0245	2.97	3.02	5

Fig. 10 Scenario comparison - Productivity

B. *Simulation Results*

Following the Arena simulation run, the outcomes were evaluated against the pre-established performance metrics. These figures were benchmarked against the specific goals for each category. Notably, the primary metric, Labor Productivity, showed a baseline value of 1.46 kg/man-hour. The simulation showed a substantial increase of 105%, setting the value to 2.99 kg/man-hour, as shown in Fig. 11. This result effectively closes the gap with the sector benchmark of 3.0 kg/man-hour.

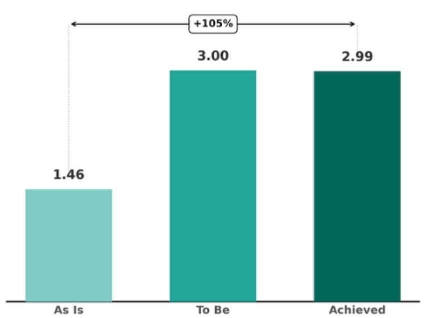


Fig. 11 Labor Productivity Indicator (kg/man-hour)

Regarding the Cycle Time indicator, there was an initial value of 21.89 minutes per batch, with a sector target of 15 minutes. The simulation exceeded expectations, reducing the cycle time to 11.87 minutes, a reduction of 46%, as shown in Fig. 12.

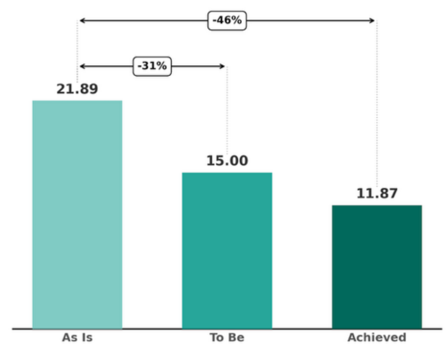


Fig. 12 Cycle Time Indicator (minutes)

In the case of the Setup Time indicator, the process initially required 82 minutes, far exceeding the Lean standard of 30 minutes. Through SMED optimization, the simulation demonstrated a reduction to 42 minutes, representing a decrease of 49%, as shown in Fig. 13.

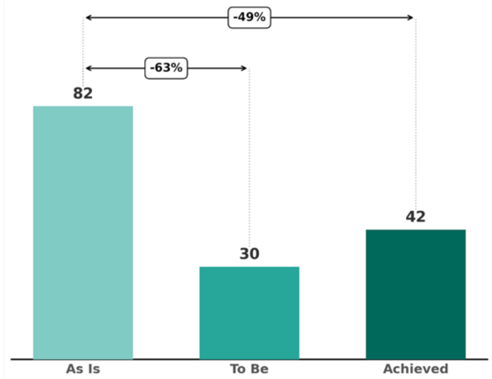


Fig. 13 Setup Time Indicator (minutes)

Finally, for the Defective Rate, there was an alarming initial value of 8.45%, with an industry acceptance limit of 3.0%. The standardization measures successfully lowered this rate to 1.20%, an improvement of 86%, as shown in Fig. 14, surpassing the quality target significantly.

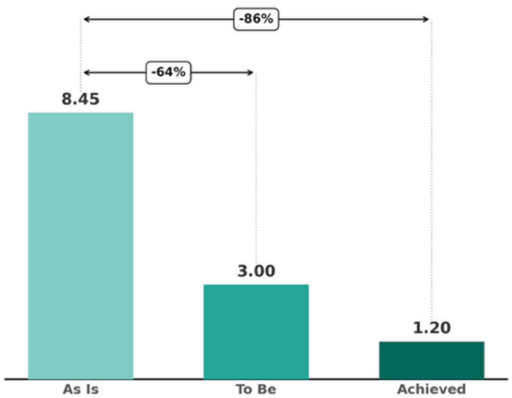


Fig. 14 Defective Rate Indicator (%)

V. Discussion

The implementation of the integrated Lean Manufacturing model yielded substantial improvements across all key performance indicators (KPIs). However, beyond the operational gains observed in this case study, the results provide significant insights when interpreted within the framework of existing literature—particularly regarding bottleneck management, setup optimization, and quality control in low-automation environments. In this regard, the study goes beyond evaluating a specific application; it examines how the structured integration of multiple Lean tools can drive quantifiable enhancements within the context of SMEs, where such combined approaches have been less frequently explored.

In the main indicator of labor productivity, the initial objective was to increase it from 1.46 to 3.0 kg/h-h, an improvement aligned with the sector standard of 3.0 kg/h-h proposed [18]. In the Arena simulation, a value of 2.99 kg/h-h was obtained, practically achieving the proposed goal with a percentage increase of 104.8%, validating the effectiveness of the integrated model.

Regarding the first component (5S Methodology), an initial audit revealed a deficient level of organization with an average score below 40%, which generated excessive search times and delays. The objective was to improve the workspace conditions to reduce the Cycle Time from 21.89 to 15 minutes, a goal consistent with the 25-30% improvement reported in similar food industries [15]. The validation results showed a reduction of the cycle time to 11.87 minutes (45.8% reduction), surpassing the expected target. This improvement confirms that the "Sort" and "Set in Order" phases effectively eliminated non-value-added movements, directly impacting the throughput of the mixing bottleneck.

In the second component (Setup Time Management), setup activities were identified and classified using the SMED methodology to separate internal from external tasks. The initial objective was to reduce the setup time from 82 to 45 minutes (45% reduction), in line with the goal in similar industries [17]. In the Arena simulation, a value of 42 minutes was obtained, which translates into a 48.8% reduction in setup time, exceeding the proposed goal. Regarding the economic impact, this improvement releases significant machine capacity, allowing the recovery of over 428,000 units per year.

In the third component (Quality and Standardization), a diagnosis of the operational errors was carried out to propose Standard Operating Procedures (SOPs) and Good Manufacturing Practices (GMP). The objective was to reduce the percentage of defective products from 8.45% to 2%, according to the 3% recommended [14]. In the Arena simulation, a defective percentage of 1.2% was obtained (reduction of 85.8%), surpassing the expectations and the sector standard. This reduction directly impacts the cost structure, lowering the unit production cost from 0.19 USD to 0.18 USD.

Although the proposed model achieved significant improvements, the development of this study faced several practical constraints. The absence of historical digital records required manual data collection, which may introduce variability in the measurements. In addition, production pressure limited the possibility of conducting full-scale pilot tests for the SMED component, restricting validation under real operating conditions. While discrete-event simulation was used to evaluate the proposed changes, further validation through real-world implementation would strengthen the robustness of the results.

At the same time, it is important to consider that the study is based on a single SME bakery case, which limits the direct generalization of the results to other industries or production environments. However, the findings provide relevant insights for similar low-automation SME contexts. Future research could address these aspects by incorporating IoT-based systems for real-time data acquisition and by implementing pilot tests in specific product lines to evaluate the long-term sustainability of the proposed Lean approach.

VI. Conclusions

This research confirms that the application of advanced Lean Manufacturing methodologies can significantly enhance the operational efficiency and competitiveness of a bakery SME. By aligning with the defined objectives, the study demonstrates the following:

First, the proposed improvement model proved effective in bridging the critical productivity gap, enabling the company to align its performance with industry benchmarks. Labor productivity increased from 1.46 kg/man-hour to 2.99 kg/man-hour, representing a 105% improvement. This outcome confirms that integrating engineering tools allows low-automation environments to maximize their throughput and resource utilization without requiring heavy capital expenditure.

Second, the implementation of the 5S methodology successfully addressed the issue of disorganized workspaces by establishing a stabilized physical environment. This technique streamlined operational flows and reduced non-value-added motions, leading to a 46% reduction in cycle time (from 21.89 to 11.87 minutes), thereby optimizing the capacity of the system's bottleneck.

Third, operational flexibility was significantly enhanced through the SMED technique. By systematically separating internal and external setup tasks and converting them, the study reduced changeover times from 82 to 42 minutes (49% reduction). This improvement directly contributed to increasing machine availability and responsiveness to demand fluctuations.

Additionally, the study underscores the importance of Standardization through visual SOPs and GMP checklists to reduce human variability. These measures lowered the defect rate from 8.45% to 1.20%, minimizing waste and ensuring consistent product quality, which is crucial for customer retention in the food industry.

The findings of this study highlight that the effectiveness of Lean Manufacturing in low-automation environments is not only dependent on the individual application of tools, but on their structured integration within a coherent improvement framework. In this sense, the proposed model demonstrates that the combined use of 5S, SMED, and process standardization can generate measurable and system-level improvements in SME bakery operations, contributing to the limited body of research focused on such contexts.

The model's long-term effectiveness remains fundamentally dependent on data quality and process discipline, with inherent limitations requiring careful consideration. At the core lies the challenge of data granularity; successful continuous improvement demands meticulously maintained production histories rather than manual record-keeping methods, which can create integration hurdles. Consequently, the continued exploration and adoption of digital tools, such as IoT sensors for real-time monitoring, are recommended to maintain momentum, overcome manual data limitations, and achieve ongoing success in a dynamic industry.

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