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Productivity Improvement in the Bread-Making Process in a Food Retail Through the Application of Lean Tools

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Abstract

This study addresses the critical issue of low productivity in the "Pan francés" line of a Peruvian food retail chain. The current productivity rate is 15.77 kg/Man-Hours (MH), falling below the sector benchmark of 17.60 kg/MH. This inefficiency results in a technical gap of 1.83 kg/MH and generates significant annual economic losses. The diagnosis identified that 67.55% of the problem is due to Loss of Availability and Operational Efficiency (mainly machine failures and cleaning delays), while 32.45% corresponds to Product Defects. Based on successful cases in the industry, an integrated Lean Manufacturing model was designed and implemented, combining Autonomous Maintenance (AM) to reduce mechanical failures, the 5S methodology to optimize cleaning times, and Standardization and Kaizen to minimize process variations and defects. The validation was performed using a hybrid method: an eight-week pilot implementation in the plant and a discrete-event simulation using Arena software (30 replicas). The results confirmed the technical efficacy of the model, showing a 25% reduction in shrinkage (from 2.2% to 1.65%), a 48.3% decrease in average cleaning time (from 60 min to 31 min), and a stabilization of machine availability. The financial analysis confirms the project's viability with a positive Net Present Value (NPV) of S/. 70,066.86. The study concludes that the integrated Lean-HACCP model is a technically sound solution for high-rotation food retail environments, translating legal compliance into operational competitive advantages.

Keywords

Lean Manufacturing, Lean tools, Autonomous Maintenance, Bread-Making industry, Standardization.

1. Introduction

The food industry in Peru constitutes a fundamental pillar of the food manufacturing economy, representing 16.52% of the sector's GDP. Within this sector, the bakery industry stands out for its dynamism; however, industrial bakeries integrated into food retail chains (supermarkets) face critical challenges related to operational efficiency. Despite having semi-automated processes, these production units suffer from low productivity, high waste rates, and frequent machine stoppages due to a lack of standardization and preventive maintenance.

In the case study analyzed, a plant supplying supermarkets nationwide, a significant technical gap in productivity was identified. The plant operates at 15.77 kg/Man-Hours (MH), a value inferior to the sector standard of 17.60 kg/MH. This inefficiency generates estimated annual economic losses derived mainly from operational overcosts and shrinkage.

The diagnosis performed using historical data analysis and the Ishikawa diagram revealed that 67.55% of the problem is due to the loss of availability and operational efficiency, caused by mechanical failures in the kneading and cutting machines (27.17%), delays in cleaning (20.19%), and inefficient task assignment. On the other hand, the remaining 32.45% corresponds to defective products generated by errors in yeast dosage, thermal failures in the oven, and over-fermentation.

1.1 Objectives

The general objective of this research is to increase productivity in the "Pan francés" production process in a food retail chain through the integrated application of Lean Manufacturing tools (Kaizen, Process Standardization, Autonomous Maintenance, and 5S). The specific objectives are:

1. To reduce mechanical failures in critical equipment (kneader and cutter) through Autonomous Maintenance.
2. To eliminate unnecessary tasks and optimize personnel flow through Standardization.
3. To decrease cleaning and setup times using 5S and Standardization.
4. To reduce the rate of defective products (shrinkage) caused by dosing errors and thermal faults using Quality Controls and Kaizen.

2. Literature Review

The systematic review of the literature confirms the efficacy of the chosen Lean tools to address the four distinct typologies of problems identified in the panification process. A critical finding is the absence of integrated frameworks that align Lean tools with specific normative engineering parameters, particularly in regulated food contexts.

2.1 Application of 5S and Standardization

Studies demonstrate that the 5S methodology is fundamental for reducing dead times due to disorganization. Aliaga-Parcco et al. (2023) evidenced that integrating 5S with the PDCA cycle in a Peruvian industrial bakery improved the work environment and reduced operational errors. Similarly, Putri et al. (2023) analyzed a case where space reorganization significantly decreased travel times.

Standardization is critical to minimizing human variability. Briceno-Pinheiro et al. (2023) highlight that formalizing procedures in bakeries improves time management and reduces waste. Furthermore, Jimenez-Ballumbrosio et al. (2023) validated that standardized work increases machine availability by reducing execution errors.

2.2 Autonomous Maintenance (TPM) and Kaizen

Autonomous maintenance, a core component of Total Productive Maintenance (TPM), establishes the operator as the first line of defense against failures. Nakajima (1988) states that autonomous maintenance empowers the operator to detect early anomalies. Muchangos and Neto (2019) confirmed that this practice improves the global performance of the productive system.

The Kaizen philosophy facilitates real-time problem resolution. Bobadilla-Calderon et al. (2022) applied a Kaizen model in a chocolate company, managing to reduce defective batches and increase production. The literature suggests that Kaizen, combined with standardization, is effective for controlling complex variables such as oven temperature and fermentation times.

3. Methods

The research methodology adopted is applied with a quantitative approach, structured in three main phases: Diagnosis, Solution Design, and Validation.

3.1 Diagnosis

In the diagnosis phase, industrial engineering tools such as the Ishikawa diagram and the Problem Tree were used to identify the root causes of low productivity (Figure 1).

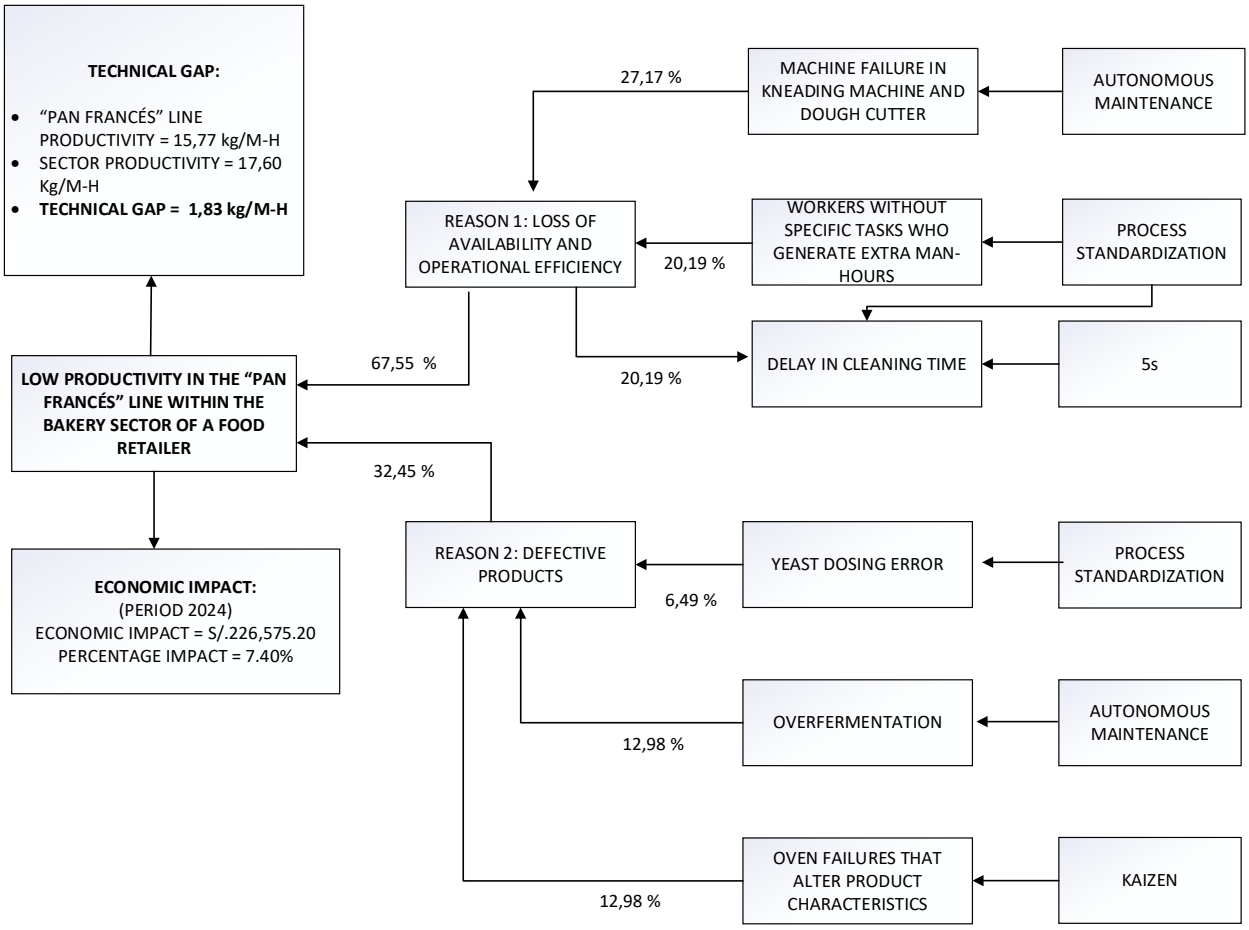

Figure 1. Problem tree

3.2 Engineering Design

The solution design was based on an integrated Production Management Model. A key innovation of this design is the establishment of a Lean-HACCP model framework. By integrating Lean tools with the sanitary regulations mandated by Peruvian law (D.S. N.º 007-98-SA), the Standardization and 5S components do not just organize the workspace but actively enforce Critical Control Points (CCP) required for food safety.

- Component 1: Focuses on the recovery of availability and efficiency through the synergistic implementation of Autonomous Maintenance (to reduce mechanical failures), Process Standardization (to optimize task assignment), and the 5S methodology (to reduce cleaning times).

- Component 2: Addresses the reduction of quality defects through the Standardization of dosing and fermentation processes, along with the implementation of Kaizen circles for the control of thermal failures in baking (Figure 2).

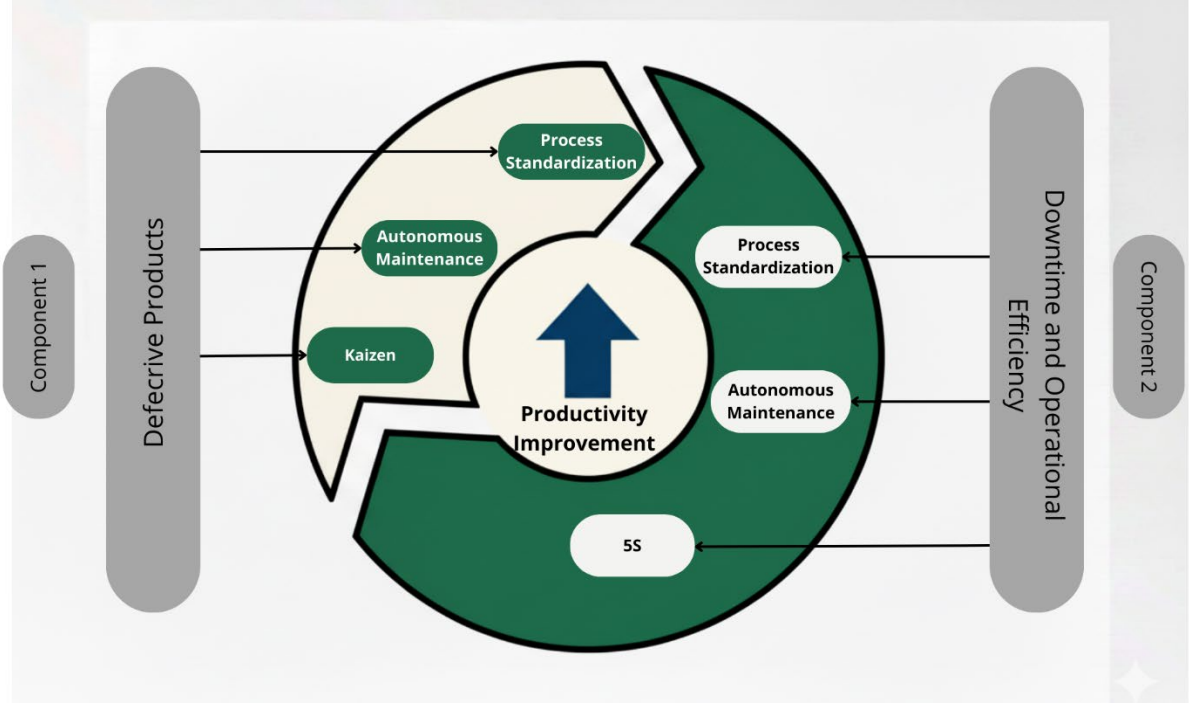

Figure 2. Engineering Model

4. Data Collection

Data collection was conducted in two fundamental stages: the establishment of the baseline (*As-Is*) and the measurement of results following implementation (*To-Be*). For the initial diagnosis, historical production records from 2024, maintenance reports, and *in situ* time measurements were collected. It was determined that the plant operated with a productivity of 15.77 kg/Man-Hours, lower than the benchmark of 17.60 kg/MH, and a monthly unproductive time of 88.92 hours, of which 34.92 hours correspond to machine failures and the rest to delays in cleaning and management. Likewise, a shrinkage rate of 2.20% was recorded, exceeding the standard of 1.50%.

For validation through simulation, failure data from critical machines (kneader and cutter) corresponding to the period from January to May 2025 were processed. Using the Arena Input Analyzer tool, probability distributions were fitted for Time Between Failures (TBF) and Time To Repair (TTR), identifying a Weibull distribution for failures and Lognormal for repairs in the base scenario.

During the pilot phase (August-September 2025), on-site data collection was carried out through daily records validated by supervisors, monitoring critical variables such as shrinkage percentage per batch, daily production in kilograms, and cleaning times per operator. These data were consolidated weekly to evaluate the performance of key performance indicators (KPIs) against projected goals (Figure 3 and Figure 4).

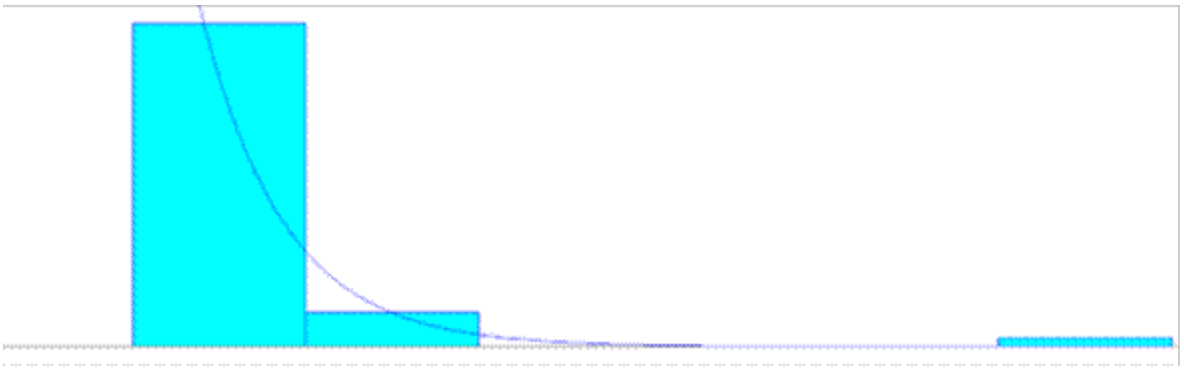

Figure 3. Input Distribution of Downtime Duration: EXPO(2.16)

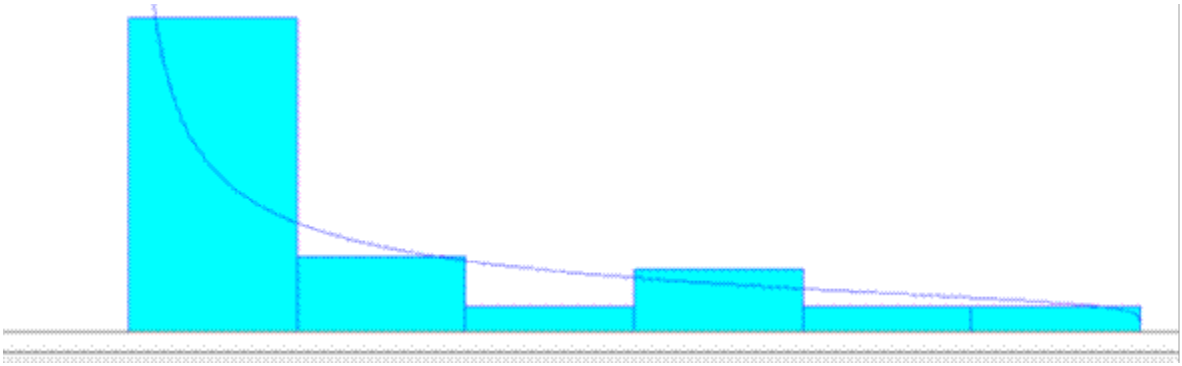

Figure 4. Input Distribution of Time Between Failures: -2 + 292 * BETA(0.435, 1.16)

5. Results and Discussion

5.1 Numerical Results (Pilot Implementation)

The pilot implementation of the Lean tools generated substantial improvements in key operational indicators. Table 1 summarizes the comparison between the projected goals and the results obtained in the plant after 8 weeks of execution. The shrinkage percentage was reduced to 1.65%, representing a relative improvement of 25% compared to the base state of 2.20%. The most significant impact was observed in the efficiency of support processes, where the cleaning time was standardized and drastically reduced from a variable average of over 60 minutes to a constant 31 minutes (Table 1).

Table 1. Projected goals vs. Pilot Results (8 Weeks)

Indicator	Metric Unit	Projected Goal	Pilot Result	Fulfillment (%)
Shrinkage (Merma)	%	1.50%	1.65%	93%
Production	KG/day	2,000	2,025	101%
Cleaning Time	Minutes	35	31	112%

5.2 Graphical Results (Simulation)

To validate the robustness of the solution against the variability of mechanical failures, a simulation was performed in Arena with 30 replicas comparing the current scenario (As-Is) with the improved scenario (To-Be).

The graphical results demonstrate a significant reduction in equipment unavailability. In the baseline scenario, the average monthly downtime was 15.71 hours with high dispersion. After the application of Autonomous Maintenance in the simulation, this value dropped to 11.19 hours/month, with a reduction in variability, confirming greater operational stability (Figure 5 and Figure 6).

Table 2. Simulation Results Comparison (As-Is vs. To-Be)

Indicator	**Mean As-Is**	**Mean To-Be**	**Standard Deviation (To-Be)**	**Unit**
Number of Failures	7.08	5.84	1.75	Failures/Month
Downtime	15.71	11.19	5.51	Hours/Month
Lost Production	1,234.74	879.54	432.89	KG/Month

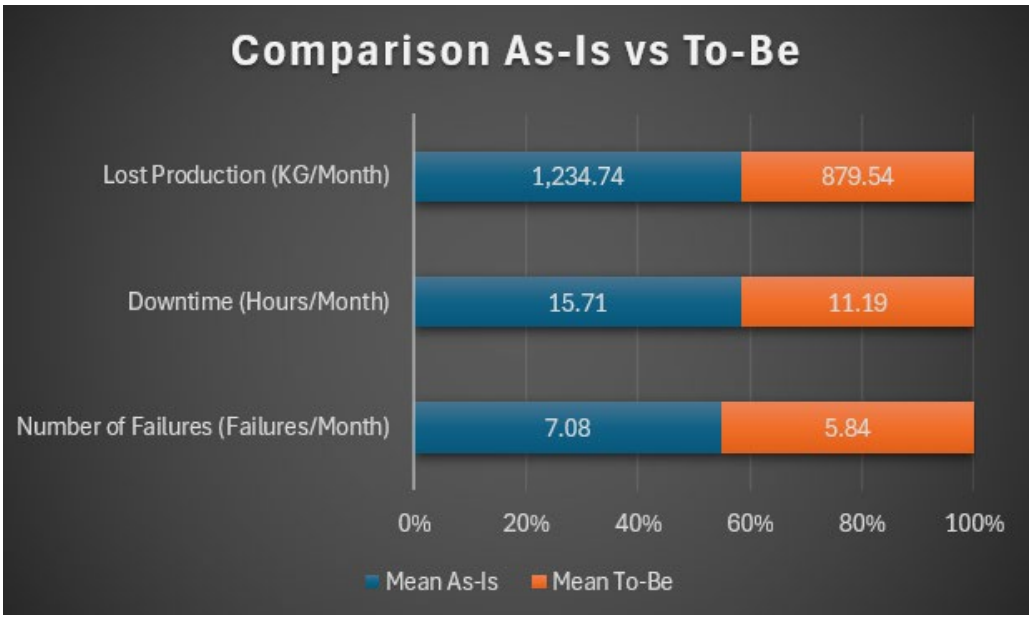

Figure 5. Comparison As-Is vs To-Be scenarios

5.3 Proposed Improvements

The proposed improvements were structured into a comprehensive model that combines four main tools to address the root causes:

- Process Standardization: Visual and laminated Standard Operating Procedures (SOP) sheets were developed for yeast dosing and cleaning, eliminating human variability and downtime caused by subjective decisions.
- Autonomous Maintenance: Daily inspection checklists (Cleaning, Inspection, Tightening, Lubrication) were implemented for the mixer and cutter, transferring the responsibility for early detection to the operator, which reduced the frequency of failures from 7.08 to 5.84 events/month.
- 5S Methodology: The layout was reorganized with visual signage and color coding, ensuring regulatory compliance (D.S. 007-98-SA) and reducing search times.
- Kaizen: Weekly quality circles were established to analyze baking defects, using visual colorimetry guides to standardize the baking point and reduce waste (Filatov et al. 2022).

5.4 Validation

The technical validation is based on the construction of a discrete event simulation model using Arena software for the autonomous maintenance tool, while pilot tests were conducted for the remaining tools. The model was designed to replicate the stochastic logic of the production line and demonstrate the robustness of the proposed solution. The model was fed with historical data fitted using the Input Analyzer, determining that the Time Between Failures (TBF) followed a Weibull distribution (−0.001 + WEIB(43.9, 0.572)) and the duration of stoppages followed a Lognormal distribution (LOGN(2.57, 3.84)).

Thirty independent replications were executed to ensure statistical stability at a 95% confidence level. As observed in Table 2, the simulation validates that the implementation of Autonomous Maintenance and Standardization reduces system variability: the standard deviation of monthly downtime decreased from 9.81 to 5.51 hours, indicating a more predictable process. Technically, this translates into a reduction in total downtime from 15.71 to 11.19 hours/month and a drop in failure frequency from 7.08 to 5.84 events/month. The convergence between these simulated results and the empirical data from the pilot confirms that the recovery of productive capacity is systemic.

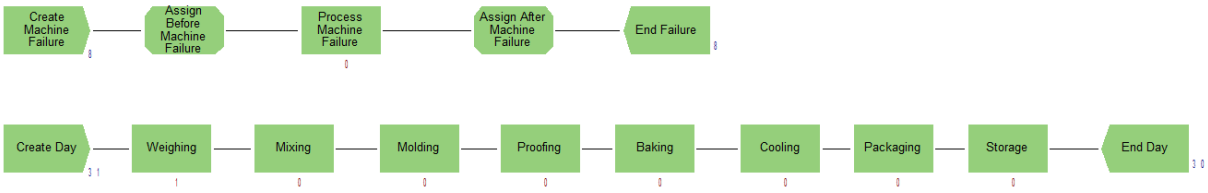

Figure 6. Arena Simulation Model

5.5 Discussion

The results obtained validate the hypothesis that the integration of Lean tools with sanitary regulations generates a synergy superior to the isolated application of methodologies. While previous studies such as that of Aliaga-Parcco et al. (2023) reported improvements in cleaning times using 5S, our research demonstrates that by linking these practices with compliance with D.S. 007-98-SA, the reduction in cleaning time (48.3%) becomes systemic and sustainable, ceasing to depend exclusively on supervision.

The analysis of the Arena simulation reveals a relevant technical finding: the reduction of the standard deviation (sigma) of downtime from 9.81 to 5.51 hours indicates that Autonomous Maintenance not only recovers productive hours but stabilizes the process, reducing operational uncertainty. This coincides with what was postulated by Nakajima (1988) regarding operator autonomy being the determining factor for variability control in critical equipment.

Likewise, the reduction of waste to 1.65% confirms that the standardization of process variables (temperature and fermentation times), and not just investment in machinery, is effective for closing quality gaps in high-turnover environments, aligning with the findings of Briceno-Pinheiro et al. (2023) for bakery SMEs. Finally, the closing of the productivity gap (increase to competitive sector levels) evidences that the root cause of the inefficiency was not technological, but rather the management of operational knowledge.

6. Conclusion

The research met the general objective by increasing productivity in the "Pan francés" line, successfully closing the identified technical gap of 1.83 kg/HH and reaching competitive sector standards. Regarding the specific objectives, it was validated that: (1) the implementation of Autonomous Maintenance effectively reduced mechanical failures in critical equipment, stabilizing operational availability; (2) Process Standardization allowed for the elimination of unnecessary tasks and the optimization of personnel flow, eliminating downtime caused by subjective decisions; (3) the combined application of 5S and standardization decreased cleaning and setup times by 48.3% (from >60 to 31 minutes); and (4) quality controls and Kaizen circles reduced the defective product rate to 1.65%.

It is concluded that Lean management, traditionally applied in mass manufacturing, is highly effective in high-diversification food retail environments when integrated with sanitary regulations. The proposed model transforms legal requirements into operational advantages, generating a cleaner, safer, and more profitable production system.

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