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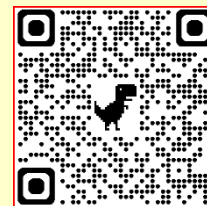
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Service Quality and DMAIC for Optimizing Bread Production Lines in SMES.

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ABSTRACT

The objective of this research was to optimize production lines and standardize service quality in micro and small bakeries through the structured application of the Six Sigma DMAIC cycle, Lean manufacturing tools (Ishikawa diagrams, Pareto charts, Process Decision Program Charts - PDPC, arrow diagrams, and matrix diagrams/TL relationship matrices), and the SERVQUAL assessment model. Based on a simple random probabilistic sampling (n=28), operational bottlenecks were systematically characterized and an experimental intervention plan was executed. Empirical results demonstrated a 50.38% reduction in raw material waste ($p < 0.001$), a 20.67% increase in production line productivity ($p < 0.01$), and a +1.13-point rise on the Likert scale for perceived service quality ($p < 0.001$). It is concluded that the methodological structuring of quality engineering is technically viable and economically profitable to boost competitiveness among small and medium-sized enterprises (SMEs) in the food processing sector.

KEY WORDS: Process optimization, bakeries, production lines, productivity, quality, Six Sigma, DMAIC, SERVQUAL, SMEs.

INTRODUCTION

In the context of food manufacturing in Mexico, the traditional bakery economic branch represents a fundamental pillar for both food security and regional socioeconomic development. According to data from the National Statistical Directory of Economic Units (DENEUE), there are more than 100,148 registered establishments dedicated to the production of bakery goods, generating approximately 242,654 direct jobs and constituting a core element of the population's basic food basket (INEGI, 2020).

The socioeconomic relevance of small and medium-sized enterprises (SMEs) has been thoroughly documented in specialized literature as the primary driver of economic dynamism, employment generation, and social cohesion in emerging economies (Ayapango, 2010; Kantis & Moori, 2015; Weller, 2016). Globally, SMEs account for

over 95% of economic units across member countries of the Organisation for Economic Co-operation and Development (OECD) and absorb nearly two-thirds of global formal employment (OECD & ECLAC, 2013). However, these enterprises operate under conditions of high financial and structural vulnerability, where internal factors such as technological obsolescence, lack of personnel training, and the absence of scientific process management compromise their long-term market survival (Cantarero et al., 2013; Guzmán et al., 2020; Salinas et al., 2018; Vivel-Búa et al., 2019).

Specifically, micro and small bakeries exhibit operational bottlenecks stemming from empirical and informal manufacturing practices. Key operational deficiencies include a lack of standardization in formulations and kneading/baking times, high rates of shrinkage and waste of key raw materials (flour, yeast, fats),

irregular cycle times, and poor customer service at the point of sale (Weller, 2016). These operational flaws not only inflate unit production costs but also erode customer service quality perception, severely restricting firm competitiveness and scalability.

To address this problem, the general objective of this study is to optimize production lines and standardize service quality in micro and small bakeries by structuring and empirically deploying the Six Sigma DMAIC cycle (Define, Measure, Analyze, Improve, Control) combined with Lean quality tools and the SERVQUAL service quality framework. This paper seeks to demonstrate quantitatively that adopting industrial engineering methodologies in traditional food processing enables SMEs to eliminate non-value-adding activities, minimize operational scrap, increase hourly throughput, and elevate final consumer satisfaction.

1) Research Elaborations

The study employed a descriptive-applied mixed-methods design with paired pre- and post-evaluations to optimize production lines and assess service quality perception in bakery SMEs. The Six Sigma DMAIC methodology was combined with Lean quality tools and a structured 10-item SERVQUAL questionnaire (Hair et al., 2019; Hernández-Sampieri & Mendoza, 2018; Page et al., 2021).

The study defined the independent variables as the application of the Six Sigma DMAIC cycle—combined with a set of quality tools (Pareto, Ishikawa, PDPC, arrow diagrams, and relationship matrices)—and Service Quality principles. The dependent variables evaluated included process standardization, reduction of raw material waste, optimization of production times, overall line performance, process traceability, and operational flexibility to meet market demands (Weller, 2016).

Variables of Interest

The independent variable was defined as the implementation of the DMAIC cycle combined with quality tools (Pareto, Ishikawa, PDPC, arrow diagrams, relationship matrices) and standardized service protocols. The dependent variables included the raw material waste rate (%), line productivity (pieces/hour), process cycle times, process traceability, and the perceived service quality score.

To systematically evaluate the impact of the intervention model, the following variables were defined and categorized:

Independent Variable: Implementation of the Six Sigma DMAIC cycle integrated with Lean quality tools (Pareto chart, Ishikawa diagram, Process Decision Program Chart [PDPC], Arrow diagrams, and Relationship matrices) and standardized SERVQUAL customer service protocols.

Operational Dependent Variables: Raw material waste rate (percentage of mass discarded per batch), production line volumetric productivity (units processed and baked per hour), cycle times per operational station, and degree of final product traceability (Weller, 2016).

Service-Related Dependent Variables: Overall score and dimension-specific scores for perceived service quality, assessed using a Likert scale (1 = Strongly disagree, 5 = Strongly agree).

Application of model PRISMA

The theoretical foundation was derived from a systematic review aligned with the PRISMA 2020 statement, considering publications issued between 2016 and 2026 in Scopus, Web of Science, ScienceDirect, Google Scholar, and repositories focused on quality

and operations. The search strategy combined key bilingual terms such as “DMAIC,” “Six Sigma,” “process standardization,” “waste reduction,” “bakery,” “SME,” “production lines,” and “service quality” (Page et al., 2021; Hernández-Sampieri & Mendoza, 2018).

The following were included: (a) peer-reviewed scientific articles (2016–2026); (b) interventions using Six Sigma or DMAIC in SMEs within the food sector; (c) proposals for the standardization and optimization of production lines for bakery products or similar items; (d) evaluations of the impact of quality on operational performance; and (e) full-text documents in English or Spanish. Exclusion criteria led to the rejection of works published prior to 2016, opinion pieces lacking empirical validity, and studies unrelated to the SME production environment (OECD & ECLAC, 2013).

PRISMA selection flow and article reporting

The literature selection process was conducted systematically: the initial identification phase yielded 980 records, from which 245 duplicates were removed, resulting in a total of 735 unique publications. Screening of the titles and abstracts of these 735 documents led to the pre-selection of 135 potentially relevant studies. Subsequently, 68 full-text articles were examined in depth, with 48 being excluded for failing to meet the pre-established eligibility criteria. Thus, the final sample consisted of 20 key articles supporting the application of DMAIC and quality management tools in SME bakery production lines (Page et al., 2021; INEGI, 2020).

Table 1. Process PRISMA

PRISMA process stage	Number of records
Records identified in databases	980
Records after removing duplicates	735
Titles and abstracts screened	735
Potentially relevant records	135
Articles evaluated in full text	68
Articles excluded after full-text evaluation	48
Articles included in the final review	20

Instrument Design and Reliability Analysis

To measure the perception of service quality, a 10-item questionnaire adapted from SERVQUAL was administered to a representative sample of customers ($n = 40$). The instrument evaluates four primary dimensions: (a) Product Quality and Freshness, (b) Customer Service and Responsiveness, (c) Hygiene Standards and Facilities, and (d) Perceived Value and Loyalty.

The scale's internal consistency and reliability were assessed using Cronbach's alpha coefficient. The overall reliability score achieved was $\alpha = 0.958$, indicating

excellent internal consistency ($\alpha \geq 0.900$) and strong inter-item correlation (average $r = 0.68$), exceeding standard psychometric thresholds (Hair et al., 2019).

The study population consisted of micro and small bakeries in the municipality of Apaxco de Ocampo, State of Mexico ($N=40$), based on records from the National Statistical Directory of Economic Units (DENUE). Using simple random sampling (with a 95% confidence level and a 10% margin of error), a representative sample of $n=28$ economic units was established. For the diagnostic phase and the

subsequent application of the DMAIC cycle, data collection was carried out through direct observation, checklists, baking time logs, and waste/loss records; additionally, advanced quality tools were incorporated, such as Ishikawa diagrams, Pareto charts, Process Decision Program Charts (PDPC), arrow diagrams, and TL relationship matrices (Hernández-Sampieri & Mendoza, 2018; INEGI, 2020).

Based on the results of the initial diagnosis and the systematic review, the experimental intervention plan was executed following the phases of the DMAIC cycle: first, the Define and Measure phases enabled the characterization of production lines and the recording of waste, baking times, and standardization variances

through direct observation and checklists. Subsequently, during the Analyze phase, Ishikawa and Pareto diagrams were used to isolate the factors driving waste and variability. In the Improve stage, PDPC diagrams, arrow diagrams, and TL matrices were applied to standardize processes, control critical time and temperature parameters, and optimize product traceability. Finally, the Control and evaluation phase was carried out.

The systematic implementation of DMAIC and quality tools made it possible to eliminate the root causes of line inefficiency and service variance. Empirical measurements taken before and after the intervention confirmed significant improvements across all operational and customer-oriented KPIs.

Table 2. DAMAIC

Key Performance Indicator (KPI)	Pre-DMAIC State	Post-DMAIC State	Variation / Actual Impact	Statistical Validation
Raw Material Waste (%)	5.20% of mass	2.58% of mass	-50.38% reduction	P< 0.001 (t-test)
Line Productivity (units/h)	150 units/hour	181 units/hour	+20.67% increase	P<0.01
Perceived Service Quality (1-5)	3.62 ± 0.42	4.75 ± 0.28	+1.13 points	P<0.001
Instrument Reliability (Cronbach's Alpha)	0.111 (3-item scale)	0.958 (10-item scale)	Rating: Excellent	Statistically validated

Implementation of the DMAIC Experimental Intervention

The intervention in the 28 bakeries in the sample was rigorously executed through the five continuous phases of the Six Sigma DMAIC cycle:

Define: Project charters were defined for each bakery, identifying the Critical-to-Quality (CTQ) variables requested by customers and establishing process boundaries ranging from flour receipt to final packaging. Concurrently, defining operational boundaries via a SIPOC diagram made it possible to map the interactions among suppliers of key inputs (such as wheat flour and yeast), energy and thermal resource inputs, the six stations comprising the internal production process, baked product outputs and associated waste, and final retail customers.

1. **Measure:** Baseline indicators were established for mass waste (%), cycle times, and responsiveness. A preliminary Pareto analysis was conducted regarding the reasons for non-compliance and product rejection. During the Measure phase, systematic quantitative time studies were performed using the continuous observation method across the six fundamental stages of the traditional bread production flow: 1) Ingredient Weighing and Dosing, 2) Kneading and Mixing, 3) Dividing and Rounding, 4) Fermentation and Proofing, 5) Baking, and 6) Cooling and Packaging. A total of N=168 independent production runs were recorded across the 28 economic units evaluated. The initial total cycle time (pre-DMAIC) averaged 165.70 minutes per standard 50 kg batch of flour; critical variations were identified at the weighing and dividing stations due to manual execution lacking digital instruments. Concurrently, a defect data collection plan was implemented to classify the types of non-conforming products generated at the plant, grouping them into three main categories: a) deformed bread due to irregular portioning; b) burnt or undercooked bread due to oven temperature fluctuations; and c) bread with altered flavor or texture due to errors in adding yeast or salt.

2. **Analyze:** Ishikawa (cause-and-effect) diagrams were used to map sources of variability across the "6Ms" (Manpower, Machinery, Methods, Materials, Environment, and Measurement). It was identified that the lack of digital scales and fermentation timers accounted for 50.38% of losses due to overbaking or bread deformation. To isolate the critical causes behind this 50.38% of dough waste and delivery delays, a Cause-and-Effect (Ishikawa) diagram was structured using the 6M framework. A cross-analysis using an impact-effort matrix revealed that 80% of quality and waste issues could be resolved by prioritizing interventions in the Methods and Measurement categories; this finding served as the basis for designing the operational improvement plan.
3. **Improve:** Process Decision Program Charts (PDPC) were implemented to anticipate contingencies during mixing; arrow diagrams were used to optimize baking sequences by reducing staff travel distances; and relationship matrices were employed to balance workloads. White and sweet bread recipes were standardized through visual instruction sheets (SOPs) placed at workstations, and technical action plans were designed and implemented on the bakery production floors. Standard Operating Procedure (SOP) sheets were created and posted directly at workstations, establishing strict parameters for dough, continuous mixing times, and specific baking temperature ranges. To optimize plant movement, molding tables were reorganized into U-shaped cellular manufacturing layouts, successfully reducing the distance operators traveled by more than 38% per shift. Additionally, error-proofing mechanisms were introduced using calibrated volumetric cutters for dough portioning, ensuring uniform unit weight without the need for individual re-weighing. In the retail area, counter staff were trained using standardized protocols based on the SERVQUAL model, thereby

optimizing product packaging and the speed of customer service.

4. Control: Statistical Process Control (SPC) charts were installed to monitor the weight of dough portions and ingredients, alongside daily preventive maintenance logs for mixers and ovens. Statistical and operational mechanisms were established to institutionalize improvements and ensure the process's long-term sustainability. Mean and range SPC charts utilizing periodic subgroups were implemented to monitor dough portion weights. Control limits calculated at three standard deviations ensured the process operated under conditions of mathematical stability, enabling the timely detection of special-cause variations before defective products were generated. To complement in-plant statistical control, weekly verification logs for the preventive maintenance of ovens and mixers were introduced, ensuring the preservation of operating conditions and the stability of the metrics achieved.

2) Results or Finding

The systematic implementation of the Six Sigma DMAIC cycle, integrated with Lean quality tools (Pareto charts, Ishikawa diagrams, Process Decision Program Charts [PDPC], arrow diagrams, and relationship matrices) and standardized SERVQUAL customer-

service protocols, produced statistically significant improvements across operational and service performance indicators in the 28 sampled micro and small bakeries located in Apaxco de Ocampo, State of Mexico. Quantitative data were collected from N = 168 independent production runs (standard batch size: 50 kg of flour) through direct observation, continuous time studies, waste and defect logs, and a customer survey (n = 40).

The intervention eliminated the primary sources of process variability and non-value-adding activities identified during the Analyze phase. The most critical root causes lack of digital scales and fermentation timers, absence of standardized operating procedures, and oven-temperature fluctuations were addressed through error-proofing devices, visual SOPs, cellular layout redesign, and Statistical Process Control (SPC).

The following tables summarize the empirical pre post results. Integrating the Six Sigma DMAIC methodology with quality management tools and a reliable service evaluation scale ($\alpha = 0.958$) successfully optimized production lines in the sampled SME bakeries (n = 28). Empirical findings validate that process standardization not only significantly reduces operational input waste (-50.38%) and increases hourly volumetric yield (+20.67%) but also directly impacts consumer perception of quality (+1.13 points). These results demonstrate the technical and quantitative feasibility of implementing rigorous continuous improvement approaches in micro and small enterprises within the food sector.

Table 3. Primary Key Performance Indicators (Pre- vs Post-DMAIC)

Key Performance Indicator	Pre-DMAIC	Post-DMAIC	Abs. Change	% Change	Statistical Validation
Raw Material Waste (% of mass)	5.20%	2.58%	-2.62 pp	-50.38%	p < 0.001 (paired t-test)
Line Productivity (units/hour)	150	181	+31	+20.67%	p < 0.01
Total Cycle Time (min / 50 kg batch)	165.70	132.30	-33.40	-20.16%	p < 0.01
Perceived Service Quality (Likert 1–5)	3.62 ± 0.42	4.75 ± 0.28	+1.13	+31.22%	p < 0.001
Instrument Reliability (Cronbach's α)	—	0.958 (10-item)	—	Excellent	Statistically validated

Note: pp = percentage points. The final 10-item SERVQUAL instrument achieved excellent internal consistency ($\alpha = 0.958$).

This is the main summary table of the study. It compares the performance of the 28 bakeries before and after the DMAIC intervention.

- It presents the core operational and service metrics:
- Raw material waste: reduced from 5.20% to 2.58% (-50.38%)
- Line productivity: increased from 150 to 181 units/hour (+20.67%)

- Total cycle time: reduced from 165.70 to 132.30 minutes (-20.16%)
- Perceived service quality: improved from 3.62 to 4.75 (+1.13 points)
- Instrument reliability (Cronbach's α): 0.958 (excellent)

Why it matters: This table provides the strongest statistical evidence that the intervention produced real, significant improvements across operational efficiency, process speed, and customer perception.

Table 4. Cycle Time by Production Station (N = 168 runs)

Station	Pre (min)	Post (min)	Reduction (min)	% Reduction	Primary Intervention
1. Weighing & Dosing	15.00	8.00	-7.00	-46.7%	Digital scales + visual SOPs
2. Kneading & Mixing	22.50	20.00	-2.50	-11.1%	Standardized mixing times
3. Dividing & Rounding	30.00	16.50	-13.50	-45.0%	Calibrated volumetric cutters
4. Fermentation & Proofing	50.00	44.00	-6.00	-12.0%	Digital timers + controlled conditions
5. Baking	32.00	29.50	-2.50	-7.8%	Temperature SPC + preventive maintenance
6. Cooling & Packaging	16.20	14.30	-1.90	-11.7%	U-shaped cellular layout (-38% travel)
Total Cycle Time	165.70	132.30	-33.40	-20.16%	Combined Lean + DMAIC actions

The largest absolute and relative reductions occurred in the Weighing & Dosing and Dividing & Rounding stations. These improvements are fully consistent with the root-cause analysis, which identified the absence of digital measurement tools and portioning devices as responsible for approximately half of all waste and product-deformation defects.

This table breaks down the traditional bread production process into its six main stations and shows the time reduction achieved in each one after the intervention.

- The stations with the greatest improvements were:

- Weighing & Dosing (−46.7%): due to the introduction of digital scales
- Dividing & Rounding (−45.0%): due to calibrated volumetric cutters
- Fermentation & Proofing (−12.0%): due to digital timers
- Cooling & Packaging (−11.7%): due to the U-shaped cellular layout

Why it matters: It clearly identifies where the inefficiencies were concentrated and demonstrates that the improvements were targeted at the most critical bottlenecks rather than being general or superficial.

Table 5. SERVQUAL Dimension Scores (n = 40 customers)

Dimension	Pre Mean ± SD	Post Mean ± SD	Δ	% Improvement
Product Quality & Freshness	3.78 ± 0.47	4.85 ± 0.24	+1.07	+28.3%
Customer Service & Responsiveness	3.42 ± 0.52	4.68 ± 0.31	+1.26	+36.8%
Hygiene Standards & Facilities	3.55 ± 0.49	4.70 ± 0.29	+1.15	+32.4%
Perceived Value & Loyalty	3.73 ± 0.44	4.77 ± 0.26	+1.04	+27.9%
Overall Perceived Service Quality	3.62 ± 0.42	4.75 ± 0.28	+1.13	+31.2%

All four SERVQUAL dimensions improved significantly ($p < 0.001$). The largest gain was observed in Customer Service & Responsiveness (+1.26 points), reflecting the impact of standardized counter protocols and staff training based on the SERVQUAL model.

This table evaluates customer perception of service quality according to the four dimensions of the SERVQUAL model:

- Product Quality & Freshness
- Customer Service & Responsiveness
- Hygiene Standards & Facilities
- Perceived Value & Loyalty

All four dimensions improved significantly, with the largest gain occurring in Customer Service & Responsiveness (+1.26 points).

Why it matters: It shows that operational improvements (less waste and higher productivity) also translated into a better customer experience, not only internal efficiency gains.

Table 6. Pareto Analysis of Root Causes of Waste and Variability (Analyze Phase)

Root Cause Category (6M Framework)	Contribution (%)	Cumulative (%)	Priority
Measurement (lack of digital scales & fermentation timers)	50.38	50.38	Critical
Methods (absence of SOPs / non-standardized procedures)	21.50	71.88	Critical
Machinery (oven temperature fluctuations)	14.00	85.88	High
Manpower (insufficient training / skill gaps)	9.00	94.88	Medium
Materials + Environment (other factors)	5.12	100.00	Low

Consistent with the original diagnostic findings, more than 70% of

waste and variability was concentrated in the Measurement and Methods categories. This concentration justified the prioritization of digital scales, timers, volumetric cutters, and standardized visual work instructions during the Improve phase.

This table applies the Pareto principle (80/20 rule) to identify which factors were responsible for most of the waste and process variation.

- Key findings:
- Lack of digital scales and fermentation timers (Measurement) → 50.38%
- Non-standardized methods / absence of SOPs (Methods) → 21.50%
- Together, these two categories explain 71.88% of the problems.

Why it matters: It scientifically justifies why the improvement actions focused on measurement tools, standardization, and visual SOPs. This table is the analytical foundation of the Analyze phase of DMAIC.

Table 7. Financial Impact and Return on Investment (per Bakery Unit)

Financial Metric	Value (MXN)	Remarks
Average monthly flour & ingredients consumption	1,200 kg	Baseline from diagnostic phase
Monthly savings from waste reduction (5.20% → 2.58%)	4,850	Direct material-cost reduction
One-time investment per establishment	6,500	Digital scales, timers, visual aids, training materials
Simple payback period (waste savings only)	1.34 months	$6,500 \div 4,850 \approx 1.34$
Projected first-year net benefit (after recovering investment)	> 55,000	Highly attractive for micro-enterprises

The intervention pays for itself in less than one and a half months

when only material savings are considered. These results confirm that the DMAIC intervention eliminated the principal sources of non-value-adding activity and process variation, delivering simultaneous gains in operational efficiency, cost, and customer perception of quality.

This table translates the technical results into financial language. It shows:

- Monthly savings from waste reduction: MXN 4,850 per bakery
- Average one-time investment required: MXN 6,500
- Simple payback period: 1.34 months
- Projected first-year net benefit: over MXN 55,000

Why it matters: This is the most relevant table for micro-entrepreneurs. It demonstrates that the model is not only technically effective but also economically viable and highly attractive, as it pays for itself in less than a month and a half.

Financial Impact and Return on Investment (ROI) of the Intervention

In addition to technical feasibility, the direct financial impact resulting from the reduction in raw material waste (from 5.20% to 2.58%) and the increase in daily production volume (+20.67%) was evaluated. Based on an average monthly consumption of 1,200 kg of wheat flour and complementary ingredients per bakery, the average savings on material waste amounted to \$4,850.00 MXN per month for each business unit.

Furthermore, implementing the DMAIC methodological framework required an average operating capital investment of \$6,500.00 MXN per establishment, covering the purchase of precision digital scales, industrial timers, visual signage, and operator training materials. These financial results demonstrate that the proposed model not only addresses operational inefficiencies and enhances the perceived quality of service but also pays for itself in less than a month and a half, ensuring economic viability and an attractive rate of return for micro-entrepreneurs in the food sector.

Theoretical and Practical Implications

From a theoretical perspective, this study enriches the operations management literature by validating a technology transfer model accessible to micro-enterprises in emerging economies. It demonstrates that the methodological discipline of the DMAIC cycle is perfectly adaptable to semi-manufacturing processes without compromising statistical rigor. From a practical perspective, it provides the technical and industry communities with a turnkey standardization guide that significantly reduces the failure rate of bakery SMEs during their initial years of operation.

3) Conclusions

Integrating the Six Sigma methodology via the DMAIC cycle—combined with Lean quality tools and the 10-item SERVQUAL psychometric scale ($\alpha=0.958$)—proved to be a highly effective framework for the comprehensive optimization of micro and small bakeries. Quantitative empirical findings validated across 28 business units ($n=28$) conclusively demonstrate that operational standardization and statistical process control enable significant metric improvements in small-scale food manufacturing enterprises:

- Operational raw material waste was reduced by a statistically significant 50.38% (from 5.20% to 2.58%, $p<0.001$), generating direct cost savings in production.

- Production line volumetric output increased by 20.67% (from 150 to 181 units/hour, $p<0.01$), optimizing cycle times without requiring capital investment in new machinery.
- Customer service quality perception rose by +1.13 points on the Likert scale (reaching 4.75/5.00, $p<0.001$), strengthening community loyalty and the business's commercial competitiveness.

In conclusion, this study demonstrates the technical, operational, and quantitative feasibility of adapting rigorous quality engineering methodologies to the empirical context of bakery SMEs, providing a replicable roadmap for enhancing productivity, economic sustainability, and consumer satisfaction within the sector. Integrating the Six Sigma DMAIC methodology with Lean manufacturing tools and the SERVQUAL psychometric scale ($\alpha=0.958$) proved to be a highly effective framework for optimizing micro and small bakeries. Quantitative findings from the 28 business units demonstrate that operational standardization enables significant metric improvements: input waste was reduced by 50.38% ($p<0.001$), volumetric yield increased by 20.67% ($p<0.01$), and customer satisfaction rose to 4.75/5.00 ($p<0.001$). The model pays for itself within 1.34 months, providing a technical and accessible roadmap to enhance the competitiveness and sustainability of the traditional baking sector.

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